Northeast Fisheries Science Center Reference Document 02-11

A Report of the Northeast Fisheries Science Center's Ecosystem Status Working Group

Status of the Northeast U.S. Continental Shelf Ecosystem

Edited by
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02-04 **Re-Evaluation of Biological Reference Points for New England Groundfish.** By Working Group on Re-Evaluation of Biological Reference Points for New England Groundfish. March 2002.

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02-06 **Report of the 34th Northeast Regional Stock Assessment Workshop (34th SAW): Stock Assessment Review Committee (SARC) Consensus Summary of Assessments.** [By Northeast Regional Stock Assessment Workshop No. 34.] April 2002.

02-07 **Report of the 34th Northeast Regional Stock Assessment Workshop (34th SAW): Public Review Workshop.** [By Northeast Regional Stock Assessment Workshop No. 34.] April 2002.

02-08 **Description of the 2001 Oceanographic Conditions on the Northeast Continental Shelf.** By M.H. Taylor, C. Bascuñán, and J.P. Manning. May 2002.

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Table of Contents

I. Executive Summary

We describe trends and conditions within the Northeastern U.S. continental shelf ecosystem. Conceptual models of ecosystem processes and working hypotheses about their interrelationships are identified. While interpreting information on the status of various ecosystem attributes is a complex process, we believe the documentation within this report provides a useful first step towards implementing ecosystem-based fisheries management (EBFM) within this ecosystem. The principal objective of this report is to characterize the state of the northeastern continental shelf ecosystem using a vast array of available data.

Most of the data in this report were collected by the Northeast Fisheries Science Center (NEFSC). The NEFSC conducts long-term scientific monitoring of trends in living marine resources, ranging from zooplankton to fish to whales, and of abiotic conditions (e.g., physical oceanography), within the Northeastern U.S. continental shelf ecosystem. The NEFSC bottom trawl survey (BTS) has been conducted since the 1960s. The BTS has used a single, standardized, depth-stratified random design to measure the distribution, abundance, and size-, and age-compositions of fish populations as well as collect oceanographic data during spring and fall seasons. Fish stomachs have been sampled during BTSs since the early-1970s to examine trophic ecology. Several other surveys (e.g., Marine Resources Monitoring, Assessment, and Prediction [MARMAP], Ecosystem Monitoring [ECOMON]) were also initiated in the 1970s to provide information on chlorophyll *a* levels, ^{14}C primary production, zooplankton and ichthyoplankton abundance, and inorganic nutrients along transects perpendicular to the coastline. Data collected during these surveys were augmented with data from the Ships of Opportunity Program (SOOP), which used continuous plankton recorders aboard commercial

vessels steaming from Boston, MA to Cape Sable, NS, Canada and from New York City to Bermuda to measure plankton and hydrographic variables. Other information was gathered from resource surveys for sea scallops, surf clams, whales, benthos, and special projects that have been conducted over the past four decades. In addition to these fishery-independent survey data, the NEFSC has collected fishery-dependent data from catch sampling at port, at-sea observer sampling, fishery logbook reports, and commercial and recreational fishery landings statistics since the 1960s. These fishery-dependent data provide the basis for many of the socio-economic factors we examine.

Substantial changes occurred within this ecosystem during the late-1970s to early-1980s when many abiotic, biotic, and human metrics exhibited coincident increases or decreases. Potential mechanisms for the observed changes are identified, with multiple working hypotheses provided where appropriate. For example, there appears to have been a shift in relative biomass between the demersal and pelagic fish communities, as demersal abundance has declined and pelagic abundance increased. Potential changes due to a shift from a cooler to a warmer temperature phase and due to a shift from low to high fishing effort may also be important.

These observations should provide the basis for future process-oriented research or multivariate approaches to further examine potential causal relationships between biotic, abiotic, and socioeconomic variables. We conclude with a list of working hypotheses which, if addressed, should help to quantify the status of this ecosystem for EBFM.

II. Introduction

A. Why this topic?

Ecosystem-based fisheries management (EBFM) has generated a lot of scientific interest in recent years (see Link 2002b for an overview). Many factors have contributed to the recent focus on EBFM, including conflict among stakeholders, conflict between legislative requirements, ongoing debate over the most important processes in marine ecosystems, and recognition of the limitations of single species management. The relative effects of multi-species predator-prey interactions, intra- and interspecific competition, and changing oceanographic conditions are important scientific issues that could hinder the near-term application of EBFM. These ongoing issues are certainly not novel (e.g., Baird 1873; Lankester 1884; Lotka 1925; Volterra 1926). Further, while several approaches to address broader considerations in a fisheries context were proposed in the 1970s and 1980s (e.g., Steele 1974; Andersen and Ursin 1977; May et al. 1979; Mercer 1982; Kerr and Ryder 1989; Daan and Sissenwine 1991), many basic issues still remain unaddressed.

Recently, some progress has been made in defining terms for EBFM, providing rationale for using a more holistic management approach, and in particular, answering when, why, and how EBFM can be practically implemented in a fisheries context (e.g., Larkin 1996; Jennings and Kaiser 1998; Hall 1999; ICES 2000; Link 2000; NMFS 2000; Link 2002a, 2002b; Brodziak and Link 2002). To date, there are few empirical descriptions of fisheries ecosystems (see, for example, AFSC; Livingston 1999, 2000). Yet the direct implementation of broader ecosystem considerations has not become widespread in fisheries management even though they have been advocated (NMFS 1999; NRC 1999; ICES 2000) and even mandated in recent years (NOAA

1996). There are no clear protocols for actually implementing EBFM and some questions of feasibility and definition are still unaddressed. However, implementation will be via iteration and sequential improvement. To this end, the Group has focused on documenting the status of the northeast U.S. continental shelf ecosystem as an essential first step to facilitate the development of an operational approach to ecosystem-based fisheries management.

B. Background of the Group

The core of our Ecosystem Status Working Group (hereafter, the Group) started out approximately in mid-1998 as a reading group for interested staff from the NEFSC to keep abreast of current issues in fisheries science and management. After reading and discussing and numerous literature articles on the subject, including Steve Hall's (1999) book on the topic, the Group realized that we could make a positive contribution towards the implementation of ecosystem-based fisheries management. Since the NEFSC has some of the world's premier time series of fisheries independent data, on subjects ranging from species abundance to zooplankton biomass to food habits to temperature, the Group thought it would be very useful to assemble these data to document the current status and recent history of the northeastern U.S. continental shelf ecosystem.

Our first objective was to assemble the diverse, multi-disciplinary sets of time series that exist at the NEFSC in detail (Table 2.1). This document describes those abiotic, biotic and human metrics. For a list of these metrics, see Table 2.1. Our second objective was to compare these metrics. We compiled these diverse datasets in common formats amenable for easy comparison. From this compilation, we produced a set of simple, common, general observations.

Our third objective was to synthesize the information into a set of working hypotheses that can serve as a basis for future detailed examinations.

C. New England fisheries: Case study for ecosystem-based fisheries management

The substantial changes in New England fisheries over the past several decades, and in particular groundfish fisheries, have been associated with excessive fishing pressure (Serchuk et al. 1994; Murawski et al. 1997; Boreman et al. 1997; NEFSC 1998a; Fogarty and Murawski 1998). The abundance of commercially desirable gadids (Atlantic cod, *Gadus morhua,* and haddock, *Melanogrammus aeglefinus*) as well as flatfish (yellowtail flounder, *Limanda ferruginea*, American plaice, *Hippoglossoides platessoides*, and winter flounder, *Pseudopleuronectes americanus*) has declined with a concurrent increase in the abundance of elasmobranchs (spiny dogfish, *Squalus acanthias*, and skates, *Raja* spp.) and small pelagic fishes. Changes in the fish community structure began occurring in the 1950s and 1960s with the arrival of distant water fleets and subsequent increase in fishing pressure exerted on the major gadid and flatfish stocks. As a result of the dramatic increase in landings (and presumably high discards), the estimated total biomass of these stocks declined by at least 50%. After the foreign fleets were displaced from the U.S. Exclusive Economic Zone (EEZ), moderate increases in stock sizes were observed in the late-1970s to early-1980s. Capacity and efficiency of the domestic fleet increased during the 1980s, however, and this led to subsequent declines in groundfish abundance. Groundfish abundance plummeted to historic lows in the 1990s, although abundances of some stocks have increased in recent years under restrictive fishery management measures. Yet some groundfish stocks, such as cod, have remained at low abundance. Many groundfish stocks on Georges Bank exhibited classic signs of overfishing in recent decades, including declines in abundance, faster growth, earlier age-at-maturity, and a truncated size structure (NEFSC 1998a, 1998b; reviewed in Jennings and Kaiser 1998). However, much less in known about the indirect and secondary effects of intense fishing pressure on the fish community in this and most marine ecosystems (Hall 1999; ICES 2000). Further, how fishing pressure affects other aspects of the northeast U.S. continental shelf ecosystem are generally not known. In this context, we hope to provide some insights on the issue of indirect effects, particularly in the context of the fishing and environmental changes that have occurred in this ecosystem.

D. Spatial delineation of northeastern U.S. continental shelf ecosystem

We use ecosystem to refer to the combination of physical processes and organisms existing within the spatial range of the system, taken together as a whole. The spatial range of the northeastern U.S. continental shelf ecosystem includes the estuarine and oceanic waters to depths of approximately 200 m from a southern boundary at Cape Hatteras, North Carolina to a northeastern boundary at the beginning of the Scotian Shelf (<100 m depth) in the northeastern Gulf of Maine through the Northeast Channel separating Georges Bank from Browns Bank and the Scotian Shelf (Figure 2.1). It is also commonly referred to as the Northeast Large Marine Ecosystem (LME; Sherman1991, Sherman et al. 1993). This ecosystem is an open oceanic system that is part of the northwestern Atlantic continental shelves province, which is a much larger oceanic region consisting of continental shelf and slope water from Florida to the Grand Banks of Newfoundland (Longhurst 1998). Within this ecosystem, we define four subdivisions with distinct hydrography and biota: the Mid-Atlantic Bight, Southern New England, Georges Bank, and the Gulf of Maine-Bay of Fundy. We will provide metrics to describe system attributes at several spatial scales, ranging from individual estuaries to subdivisions to the entire northeastern U.S. continental shelf ecosystem.

E. Temporal extent and resolution

Many of the metrics we examined are derived from the NEFSCs spring and fall bottom trawl survey (Grosslein 1969; Azarovitz 1981; NEFC 1988). These extend back to 1968 and 1963, respectively, and are maintained to the present time. Several other time series (e.g., MARMAP, SOOP, food habits, vessel landings) are available for the same time period. We present a suite of over 100 metrics, many of which span 25 - 40 years (Table 2.1). Metrics with short time series have been included even though they may represent only snapshots of particular system attributes, however, most of the metrics provide information on annual or interannual time scales. Although some data were available to examine seasonal contrasts, we did not require this level of resolution to document the status of the ecosystem.

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Table 2.1. Metrics we examined in this study and the extent of these time series. Source includes the principal researcher and the programmatic source of the data; BTS = bottom trawl survey, SS = scallop survey, SHS = Sandy Hook estuarine survey, FH = food habits, ZP = zooplankton, OBS = observer and port agent commercial landings database, OCE = oceanographic database, MAM = mammal survey, REG = regulations implemented, MAR = MARMAP Ships of Opportunity Program. The general process indexed by each metric is also listed.

SOURCE	WHAT IS IT?	START YEAR	END YEAR	YEARS IN SERIES	FIGURE NUMBER	PROCESS INDEXED
ABIOTIC METRICS						
BRODZIAK OCE	NAO Index	1823	2000	177	A.1	Long-term Forcing
BRODZIAK OCE	5-Year Average of NAO Index	1823	2000	177	A.2	Long-term Forcing
MOUNTAIN BTS	Shelf-Wide Surface and Bottom Water Temperature Anomalies, Autumn Survey	1963	2000	37	A.3	Forcing Physics
MOUNTAIN BTS, OCE	MAB Shelf Water Anomalies for Volume, Salinity, and Temperature	1977	2001	24	A.4	Forcing Physics
MOUNTAIN, BRODZIAK BTS, OCE	Surface and Bottom Temperature Anomalies	1963	2000	37	A.5	Forcing Physics
MOUNTAIN BTS	Average MAB Shelf Water Temperature Anomaly in 1990s for Five Regions	1990	1999	9	A.6	Forcing Physics
JOSSI OCE, ZP	Massachusetts Bay Anomalies from 1978-90 Averages of Surface Temperature, Salinity, and Bottom Temperature from a Fixed Transect	1978	2001	24	A.7	Forcing Physics
JOSSI OCE, ZP	MAB Anomalies from 1978-90 Averages of Surface Temperature, Salinity, and Bottom Temperature from a Fixed Transect	1978	2001	24	A.8	Forcing Physics
JOSSI BTS	Western Gulf of Maine Surface and Bottom Temperature and Salinity Anomalies	1978	2001	24	A.9	Forcing Physics
MOUNTAIN BTS, OCE	Georges Bank NAO, Salinity, Plankton and Cod	1970	1996	26	A.10	Long-term Forcing, Forcing Physics
BIOTIC METRICS						
HART BTS, SS	Georges Bank Scallop Biomass Density	1980	2000	20	B.1	Benthic Dynamics, “Canary” Populations

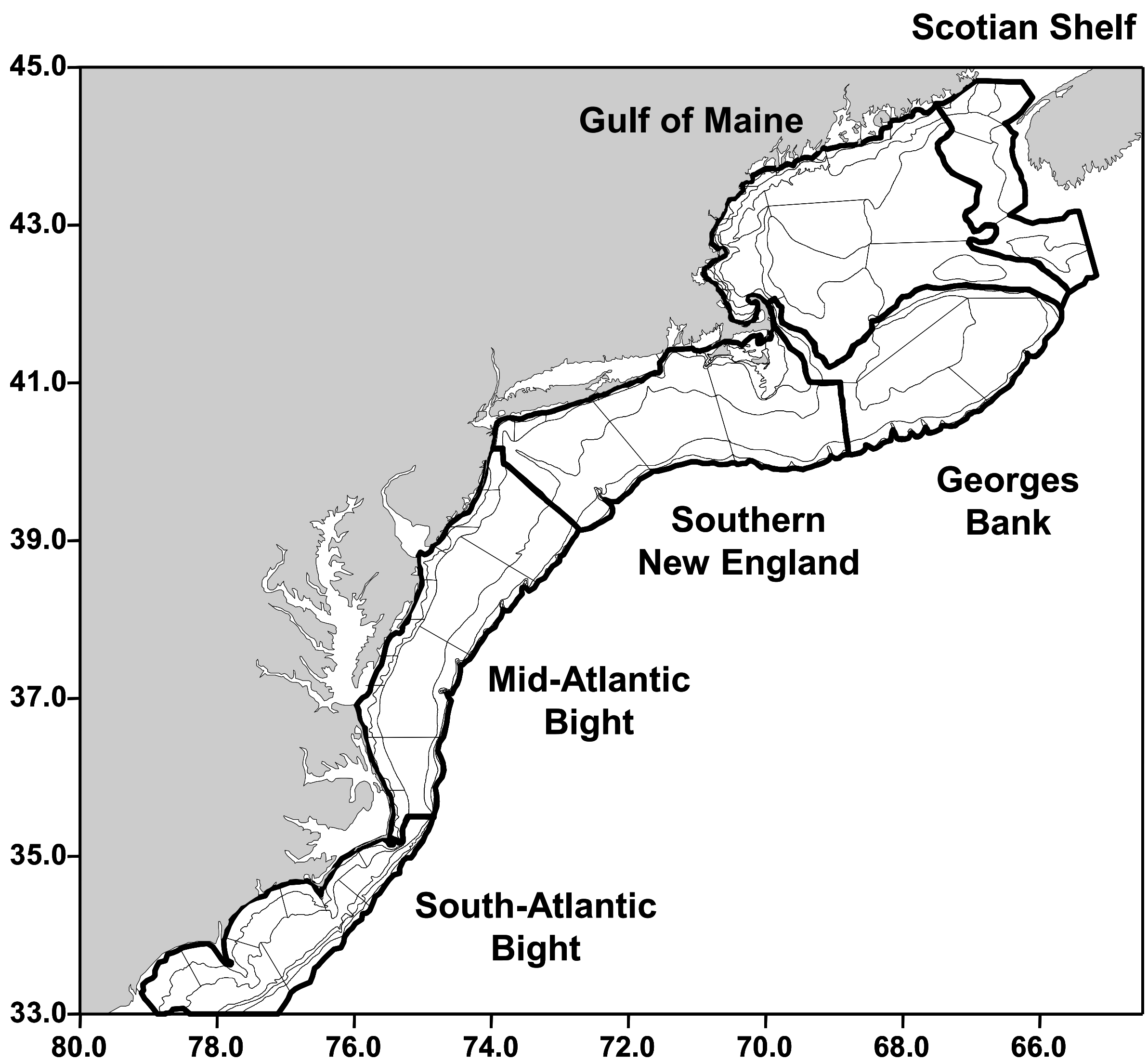
HART BTS, SS	Mid Atlantic Scallop Biomass Density	1980	2000	20	B.2	Benthic Dynamics, “Canary” Populations
HART BTS, OBS, SS	Georges Bank Scallop Survey Biomass and Landings	1962	1999	37	B.3	Benthic Dynamics, “Canary” Populations
HART BTS, OBS, SS	Mid Atlantic Scallop Survey Biomass and Landings	1962	1999	37	B.4	Benthic Dynamics, “Canary” Populations
LINK BTS	Sculpin mean number per tow on Georges Bank autumn NEFSC survey	1963	1998	35	B.5	Benthic Dynamics, “Canary” Populations
FABRIZIO SHS	Beam and Otter Trawl Catch of Blue Crab per Unit Area in an Estuary	1996	2000	4	B.6	Benthic Dynamics, “Canary” Populations
JOSSI ZP	GOM Percentile Anomalies of Calanus from 1961-90 Median	1961	2000	40	B.7	Secondary Production
JOSSI ZP	Anomalies of major zooplankton taxa	1977	1996	19	B.8	Secondary Production
JOSSI ZP	Spatio-seasonal density of Centropages across continental slope	1976	1990	14	B.9	Secondary Production
JOSSI ZP	Seasonal Calanus Abundance, Between Massachusetts and Cape Sable	1961	1998	37	B.10	Secondary Production
KANE ZP	Anomalies of Georges Bank Total ZooplanktonBiomass and Abundance for 2 major copepods	1977	2000	23	B.11	Secondary Production
KANE ZP	Anomalies of Gulf of MaineTotal ZooplanktonBiomass and Abundance for 2 major copepods	1977	2000	23	B.12	Secondary Production
KANE ZP	Mean Zooplankton Biomass, entire shelf	1977	2000	23	B.13	Secondary Production
NEFSC BTS	Groundfish, principal pelagics, dogfish & skates, and other fish	1963	1999	36	B.14	Aggregate Production, Biomass Allocation
BRODZIAK BTS	Georges Bank Principal Groundfish Abundance	1963	1999	36	B.15	Aggregate Production
BRODZIAK BTS	Georges Bank Elasmobranch Abundance	1968	1999	31	B.16	Aggregate Production
BRODZIAK BTS	Principal Pelagics Abundance	1967	1994	27	B.17	Aggregate Production
BRODZIAK BTS	Georges Bank Cephalopod Abundance	1963	1999	36	B.18	Aggregate Production

LINK FH	Frequency of parasite occurrence by predator	1973	1998	25	B.19	Trophic Dynamics, Density Dependence
FABRIZIO SHS	Beam and Otter Trawl Catch of Winter Flounder per Unit Area in an Estuary	1996	2000	4	B.20	Population Dynamics
NEFSC BTS	Percent mature at age-1 & age-2 for GB haddock and cod	1963	1997	34	B.21	Population Dynamics, Allometric Dynamics
BRODZIAK BTS	Georges Bank Cod Recruits per Spawner Anomalies	1978	1998	20	B.22	Recruitment Dynamics
BRODZIAK BTS	Georges Bank Haddock Recruits per Spawner Anomalies	1931	1998	67	B.23	Recruitment Dynamics
BRODZIAK BTS	Georges Bank Yellowtail Recruits per Spawner Anomalies	1973	1998	25	B.24	Recruitment Dynamics
LINK BTS	Swept-Area Total Biomass Index	1963	1999	36	B.25	System Production
LINK BTS	Mean animal length on Georges Bank from NEFSC bottom trawl surveys	1963	2000	37	B.26	Allometric dynamics
LINK BTS	Swept-Area Biomass Index by different Guilds	1963	1999	36	B.27	Aggregate Production
BRODZIAK BTS	Gulf of Maine Total Species Diversity	1963	2000	37	B.28	Diversity, Biomass Allocation
BRODZIAK BTS	Gulf of Maine Abundant Species Diversity	1963	2000	37	B.29	Diversity, Biomass Allocation
BRODZIAK BTS	Gulf of Maine Species Evenness	1963	2000	37	B.30	Diversity, Biomass Allocation
BRODZIAK BTS	Georges Bank Total Species Diversity	1963	2000	37	B.31	Diversity, Biomass Allocation
BRODZIAK BTS	Georges Bank Abundant Species Diversity	1963	2000	37	B.32	Diversity, Biomass Allocation
BRODZIAK BTS	Georges Bank Species Evenness	1963	2000	37	B.33	Diversity, Biomass Allocation
BRODZIAK BTS	Mid-Atlantic Bight Total Species Diversity	1963	2000	37	B.34	Diversity, Biomass Allocation
BRODZIAK BTS	Mid-Atlantic Bight Abundant Species Diversity	1963	2000	37	B.35	Diversity, Biomass Allocation
BRODZIAK BTS	Mid-Atlantic Bight Species Evenness	1963	2000	37	B.36	Diversity, Biomass Allocation
LINK FH	Silver Hake Linkage Density	1973	1999	26	B.37	Trophic Dynamics, Energy Flow

OVERHOLTZ BTS, FH	Total Biomass Consumption by 12 piscivores	1977	1997	20	B.38	Biomass Allocation, Energy Flow
LINK BTS, FH	Total fish consumption of 6 piscivores on Georges Bank	1977	1998	21	B.39	Biomass Allocation, Energy Flow
OVERHOLTZ FH, BTS	Consumption of 6 pelagic species by 12 predators	1977	1997	20	B.40	Biomass Allocation, Energy Flow
LINK FH	Food web 1977	1977	1977	1	B.41	Trophic Dynamics, Energy Flow
LINK FH	Food web 1987	1987	1987	1	B.42	Trophic Dynamics, Energy Flow
LINK FH	Food web 1997	1997	1997	1	B.43	Trophic Dynamics, Energy Flow
LINK FH	Cod fish consumption and percent fish in diet	1978	1997	19	B.44	Trophic Dynamics
LINK FH	Cod fish consumption by age class	1978	1997	19	B.45	Trophic Dynamics
LINK FH	Cod percentage diet composition of major fish prey	1973	1997	24	B.46	Trophic Dynamics
LINK FH	Spiny dogfish percentage diet composition of major fish prey	1977	1997	20	B.47	Trophic Dynamics
LINK FH	No. Predators of Major Species	1973	1999	26	B.48	Trophic Dynamics
LINK FH	Silver Hake Cannibalism	1973	1999	26	B.49	Trophic & Population Dynamics, Cycling
LINK FH	Silver and Red Hake Number of Prey	1973	1999	26	B.50	Trophic Dynamics, Energy Flow
OVERHOLTZ FH, BTS	Atlantic Herring Biomass Versus Consumption of Herring by 12 Predators	1977	1997	20	B.51	Biomass Allocation, Energy Flow
OVERHOLTZ FH, BTS	Atlantic Mackerel Biomass Versus Consumption of Mackerel by 12 Predators	1977	1997	20	B.52	Biomass Allocation, Energy Flow
OVERHOLTZ FH, BTS	Loligo Biomass Versus Consumption of Herring by 12 Predators	1977	1997	20	B.53	Biomass Allocation, Energy Flow
JOSSI & O'REILLY MAR	U.S. Northeast Continental Shelf Chlorophyll a	1977	1988	-	N/A	Primary Production
PALKA & SMITH MAM	Abundance of various marine mammals	various		-	Table 4.1	Apex Predators, Population Dynamics, “Canary” Populations
HUMAN METRICS						
EDWARDS OBS	Otter Trawl Landings by Species	1964	2000	36	H.1	Humans as Predators
EDWARDS OBS	Otter Trawl Revenue by Species	1964	2000	36	H.2	Humans as Predators
EDWARDS OBS	Number of Otter Trawl Vessels by Size Class	1964	2000	36	H.3	Humans as Predators

EDWARDS OBS	Otter Trawl Income in Year 2000 Value	1964	2000	36	H.4	Humans as Predators
EDWARDS OBS	Average Otter Trawl Income in Year 2000 Value	1964	2000	36	H.5	Humans as Predators
BRODZIAK OBS	Georges Bank Fishing Effort	1960	1987	27	H.6	Humans as Predators
BRODZIAK OBS	Georges Bank Catch per Unit Effort	1960	1987	27	H.7	Humans as Predators
BRODZIAK OBS, REG	Georges Bank Haddock Observed and Target Fishing Mortality	1931	1998	67	H.8	Human Management
BRODZIAK OBS	Georges Bank cod, haddock, and yellowtail yields	1935	2000	65	H.9	Humans as Predators
OLSON OBS	Total days absent by state of landing	1999	1999	1	H.10, H.11	Human Behavior, Spatial Dynamics
OLSON OBS	Summer flounder catch sites by state of landing and size of catch	1999	1999	1	H.12	Human Behavior, Spatial Dynamics
OLSON OBS	NE Landed Value by County	1994	2001	7	H.13	Human Behavior, Spatial Dynamics
OLSON OBS	NE Number of Federal Permits by County	1997	2001	4	H.14	Human Behavior, Spatial Dynamics
OLSON OBS	Average Days Absent by Location	1999	1999	1	H.15	Human Behavior, Spatial Dynamics
OLSON OBS	Groundfish Landings by Stat Area	1995	2000	5	H.16, H.17	Human Behavior, Spatial Dynamics
OLSON OBS	Pelagics Landings by Stat Area	1995	2000	5	H.18, H.19	Human Behavior, Spatial Dynamics
LINK/EDWARDS OBS	NE Bigeye tuna landings and revenue	1993	1997	4	H.20	Humans as Predators
LINK/EDWARDS OBS	NE Cod landings and revenue	1993	1997	4	H.21	Humans as Predators
LINK/EDWARDS OBS	NE Swordfish landings and revenue	1993	1997	4	H.22	Humans as Predators
BRODZIAK REG	Trawl Fishery Area Closures	1977	2000	23	H.23	Human Management
BRODZIAK REG	Trawl Fishery Mesh Restrictions	1977	2000	23	H.24	Human Management
BRODZIAK REG	Groundfish Vessel Days at Sea Restrictions	1977	2000	23	H.25	Human Management

Figure 2.1. Map of the northwest Atlantic, including the major subregions.



III. ABIOTIC METRICS

A. Geology, Chemistry

Geologic and chemical features significantly influence the physical and biological components of this ecosystem. Although data on these factors exists, few time series are available.

We do not include geological metrics in this report because the extant data and expertise in this area reside with the United States Geological Survey. From an ecosystem perspective, we need definitions of major geologic regions, including the distributions of major sediment/bottom types, and delineations of high/low energy areas in the ecosystem. Some information on the marine geology of the region is summarized in Backus (1987). Time series of geological characteristics may not be essential for understanding ecosystem dynamics, particularly in the context of living resources. Because these issues are beyond our expertise, they should be considered (and currently are) in collaboration with the USGS.

In the case of chemical metrics, we need to identify key chemical indicators from an array of important nutrients, metals, and toxins. We also need to be able to track their concentrations through time and space. Few time series data exist for these chemicals. Some chemicals have been sampled by our Highlands, NJ Lab over time at particular locations. However, we do not know the spatial extent and resolution of sampling needed to synoptically understand how these chemicals influence ecosystem dynamics. Important questions to address include:

how often do we need to sample, what selection of representative chemicals should we monitor, and what are the major gaps of information? These questions need to be addressed before we can develop chemical metrics for this ecosystem.

B. Physics

1. NAO Index

Time: 1823-2000

Spatial: North Atlantic Ocean

Contributed by: Brodziak

Figures A.1 and A.2

Methodology and Data Source

The NAO index is calculated as the air pressure difference between sites in Iceland and southern locations at the Azores or Gibralter (Jones et al. 1997). The NAO index time series was computed using data available from the Climate Research Unit at the University of East Anglia. This data may be accessed at http://www.cru.uea.ac.uk/. The NAO winter index is reported here. In year y, the NAO winter index is the arithmetic average of monthly NAO values for December in year y and January-March in year y+1. The winter index is available for 1823-2000. The five-year moving average of the NAO index in year y is computed as the arithmetic average of NAO values in years y-2, y-1, y, y+1, and y+2; the five-year average is available for 1825-1998.

Key Points and Major Observations

The North Atlantic Oscillation (NAO) is one of the major features of the global climate system. There is an upward trend in the NAO from the 1960s to the early 1990s. The NAO index is highly variable and the largest recorded interannual change in the NAO index occurred from 1994 to 1995. The latitude of the Gulf Stream has been correlated with the NAO over the last 30 years (Taylor et al. 1998). Large positive NAO values are associated with colder air and stronger winds over the North Atlantic and a larger cold intermediate water layer on the Labrador Shelf. Large negative NAO values are associated with warmer air and weaker winds over the North Atlantic and a smaller cold intermediate water layer on the Labrador Shelf.

2. Shelf wide Temperature anomaly

Time: 1963-2000

Spatial: Shelf wide

Contributed by: Mountain

Figure A.3

Methodology and Data Source

These are the surface and bottom temperature anomalies for NMFS fall bottom trawl survey, averaged over the whole shelf region from Cape Hatteras through the Gulf of Maine (Holzwarth and Mountain 1992; Taylor and Bascunan 2001). For each temperature observation made on a survey, its anomaly was determined by comparison with annual cycles of temperature derived from the MARMAP program (1978-1987). This procedure takes into account the day of the year on which the observation was made and its specific location. All of the anomaly values for a survey were averaged on an area weighted basis to determine the values plotted.

Key Points and Major Observations

The variability of 2-4 degrees C has been consistently observed over the past four decades. The late 1960s were a particularly cold period. The 1990s appear to be slightly warmer than preceding decades.

3. MAB Volume, Salinity & Temperature anomaly

Time: 1977-2000

Spatial: Mid-Atlantic Bight

Contributed by: Mountain

Figure A.4 (a-c)

Methodology and Data Source

The volume and average temperature and salinity of Shelf Water in the MAB have been determined for each NEFSC cruise that made temperature and salinity observations through the MAB area (Mountain 1991). Shelf Water is defined as water with salinity < 34 PSU, and is in contrast to the oceanic Slope Water that is found seaward of the shelf/slope front. From the surveys averaged values for the volume, temperature and salinity of Shelf Water in the MAB, annual cycles were derived for each variable. Anomalies for each variable were determined relative to these characteristic annual cycles

Key Points and Major Observations

There is very large variability in the amount of Shelf Water in the MAB. Additionally, there is large variability in the salinity of the Shelf Water in the MAB. The Shelf Water volume in the 1990s was substantially higher than in the 1980s and the salinity in the 1990s was lower than in the 1980s. The source of the volume and salinity variations is largely advective from the Gulf of Maine – and from variation in the inflows to the Gulf.

4. Surface and Bottom Temperature anomalies

Time: 1963-2000

Spatial: All the major subregions

Contributed by: Mountain, Brodziak

Figure A.5 (a-h)

Methodology and Data Source

These are the surface and bottom temperature anomalies for NMFS bottom trawl survey, averaged for each of the major subregions (Holzwarth and Mountain 1992; Taylor and Bascunan 2001). For each temperature observation made on a survey, its anomaly was determined by comparison with annual cycles of temperature derived from the MARMAP program (1978-1987). This procedure takes into account the day of the year on which the observation was made and its specific location. All of the anomaly values for a survey were averaged on an area weighted basis to determine the values plotted.

Key Points and Major Observations

There is large variability in the surface and bottom temperatures in each region. The late 1960s were a particularly cold period. Little trends are observed in any region through the 1970s and 1980s, although there may be slightly warmer waters in the 1990s for a few regions. The differences between the regions show no consistent pattern.

5. MAB Temperature anomalies, by 5 provinces

Time: 1990s, Annual, composite average

Spatial: Mid-Atlantic Bight

Contributed by: Mountain

Figure A.6

Methodology and Data Source

The shelf water temperature anomalies during the 1990s for five regions of the MAB (from north to south) have been averaged for three periods of the year (in essence, for thirds of the year) (Mountain 2001). The anomalies are relative to the MARMAP period (1978-1987). The methods for determining the shelf water anomalies were describe earlier.

Key Points and Major Observations

During the winters of the 1990s the MAB became progressively warmer from north to south as compared to the MARMAP period. The summer period exhibited some cooling in the central MAB. The fall period was generally a bit warmer than the MARMAP period. Overall, the MAB was about 1 C warmer in the 1990s than during the MARMAP period.

6. Massachusetts Bay Surface Temperature, Surface Salinity, Bottom Temperature Anomalies

Time: 1978-2000

Spatial: Massachusetts Bay

Contributed by: J. Jossi

Figure A.7

Methodology and Data Source

These data were collected as part of the MARMAP Ships of Opportunity Program (Benway et al. In Review; Jossi et al. In Review). Expendable bathythermograph and surface salinity measurements were taken monthly by merchant vessels between Boston, MA and Cape

Sable, NS. Values were gridded in time and space (distance along transect). Grids of long term means and standard deviations; and single year conditions, anomalies, and standardized anomalies are produced. Grids were sliced through time at a distance representing Massachusetts Bay for this portrayal, which also shows a smooth curve based on a 15 month running average (Benway et al 1993). The location chosen to represent Massachusetts Bay was at 48 km reference distance, or approximately 70º 20'W, along the transect.

Key Points and Major Observations

Surface Temperature- With the exception of isolated monthly departures near, or in excess of two standard deviations, the period 1978 through 1988 exhibited no enduring anomalous surface temperatures. From 1992 to mid-1994 mostly colder than average conditions prevailed. No trend during the time period was apparent.

Surface Salinity- Salinities generally increased from 1978 through 1980, declined through 1984 to a period minimum, rose sharply in 1985, were below average in 1987, and after 1990 they again declined to the end of the sampling period in 1993. The longest sustained anomalous period was that of low salinities in 1983 and 1984.

Bottom Temperature- From 1978 to 1981 values were near normal. Higher temperatures occurred during 1982 and 1983 followed by near average values in the mid-1980s. From 1987 through 1990, and 1992 to 1994 values were generally negative, after which departures became inconsistent, with several significantly warm months. Departures in the late 1990s were more excessive than in the earlier period, and might result in a warming trend for these data.

7. Mid-Atlantic Bight Surface Temperature, Surface Salinity, Bottom Temperature Anomalies

Time: 1978-2000

Spatial: Mid-Atlantic Bight and mid-Continental Shelf

Contributed by: J. Jossi

Figure A.8

Methodology and Data Source

These data were collected as part of the MARMAP Ships of Opportunity Program (Benway et al. In Review; Jossi et al. In Review). Expendable bathythermograph and surface salinity measurements taken monthly by merchant vessels along a transect from New York City towards Bermuda to the Gulf Stream. Values were gridded in time and space (distance along transect). Grids of long term means and standard deviations; and single year conditions, anomalies, and standardized anomalies are produced. Grids were sliced through time at a distance representing the continental shelf, generally unaffected by river runoff and/or slope water, for this portrayal. The portrayal also shows a smooth curve based on a 15 month running average (Benway et al. 1993). The location chosen to represent the Middle Atlantic Bight was at 101 km reference distance, or approximately 40° N; 73° W, along the transect.

Key Points and Major Observations

Surface Temperature- Isolated months through the 1978-2000 time period exhibit significant departures from the 1978-1990 means. Departures in excess of 2 standard deviation were more numerous in the 1990s than in the previous years, even after adjustments to account for the 1990s not being included in the base period. Sequential, monthly positive or negative departures were more consistent in the 1990s than in previous years. Finally, the surface temperatures appear to be trending upwards between 1978 and 2000.

Surface Salinity- Isolated months exhibit significant departures during the time period, and are more prevalent in especially the late 1990s than earlier periods. There is more month-to-month consistency of the surface salinity departures than of the surface temperatures. Uninterrupted positive departures of two years (1980-1981; 1985-1986; 1994-1995), and negative departures of two to three years (1996-1998; 1998-1999) occurred. No trend during the time period was apparent.

Bottom Temperature- Greater departures in the 1990s also occurred in the bottom temperature data. Aside from beginning the time period in a negative phase and ending in a positive phase, a possible trend is not as clear as with surface temperature. However, the phase changes of the smoothed values are quite similar through the time period for these two features.

8. W. Gulf of Maine Surface Temperature, Surface Salinity, Bottom Temperature Anomalies

Time: 1978-2000

Spatial: Gulf of Maine

Contributed by: J. Jossi

Figure A.9

Methodology and Data Source

These data were collected as part of the MARMAP Ships of Opportunity Program (Benway et al. In Review; Jossi et al. In Review). Expendable bathythermograph and surface salinity measurements taken monthly by merchant vessels along a transect from Boston, MA to Cape Sable, NS.. Values were gridded in time and space (distance along transect). Grids of long term means and standard deviations; and single year conditions, anomalies, and standardized anomalies are produced. Grids were sliced through time at a distance representing approximately Wilkinson Basin for this portrayal. The portrayal also shows a smooth curve based on a 15 month running average (Benway et al. 1993). The location chosen to represent the western Gulf of Maine was at 165 km reference distance, or approximately 68° 55' W along the transect.

Key Points and Major Observations

Surface Temperature- Variations from 1978 through 1990 followed a similar pattern to those for surface temperature in Massachusetts Bay, except that they were of slightly larger magnitude. High values occurred from 1983 to 1985, and low values occurred in 1982, for a fairly prolonged period from 1986 to 1991, and again from mid-1991 to 1994. This was followed in 1996 and 1997 by the lowest temperatures of the period, from which point temperatures began increasing to reach the highest values of the period by 2000. Neither of these last two conditions were seen to any extent in Massachusetts Bay. No trend was apparent, although the last four years of the period exhibited a dramatic increase.

Surface Salinity- The western Gulf of Maine surface salinity pattern follows that of Massachusetts Bay very closely. The only major exception was that in the western Gulf of Maine the 1985 high persisted to the beginning of 1987. No trend was apparent during the time period.

Bottom Temperature- Patterns here were also very similar to those for bottom temperature in Massachusetts Bay, although the departures were of less magnitude. Time period low occurred in late-1994 followed by the series high in 1995. Similarly, variations were larger in the late-1990s than earlier in the period. No trend was apparent.

9. Relationships Among NAO, Salinity, Plankton, and Cod on Georges Bank

Time: 1970-1996

Spatial: Georges Bank

Contributed by: Mountain

Figure A.10

Methodology and Data Source

The early spring plankton displacement volume on Georges Bank is compared with a detrended, inverted NAO series and with salinity variability on the bank (Mountain et al. 2000). A cod survival index (ratio of the number of recruits to the spawning stock biomass, with both series hanned before the ratio was taken) is also compared with the detrended NAO series. The plankton displacement volume series was determined by J. Kane from the Center's plankton survey data. The salinity anomalies were derived from the Center temperature and salinity data, relative to annual cycles of salinity derived from the MARMAP data set. The cod series were from stock assessment documents. The NAO was from a NAO website. The method was straight forward of plotting the predetermined series.

Key Points and Major Observations

The displacement volume appears to follow the detrended NAO and the salinity variability quite well. There are large interannual differences in the displacement volume. The cod survivorship series also seems to follow the NAO quite well. There are no obvious processes that connect these series.

C. Summary of Abiotic Metrics

Various graphics of temperature and salinity data from Ship-of-Opportunity (SOOP) data and shelfwide research cruise data were examined. Preliminary examination of the average of surface and bottom temperatures from the Autumn Bottom Trawl data, shelf-wide for all regions from Cape Hatteras to Nova Scotia, showed the 1960s were cold and the remaining years were variable without any apparent trend. It is questionable if the 1990s were slightly warmer than preceding decades. When these data are sorted out spatially into subregions, they exhibit a similar pattern.

Data on the volume of water, salinity and temperature were examined for the Mid-Atlantic Bight (MAB) shelf water inside the shelf/slope boundary. In the 1990s, the following were observed: 1) a 25-30% increase in the amount of shelf water volume in the Bight was apparent over that of the long term mean; 2) salinity was lower in the 90s; similar to observations made for northwestern Georges Bank; and 3) temperature was about 1 degree warmer in the 90s.

The MAB data were broken out into shelf sectors (SNE, NYB1, NYB2, SS1, SS2, north to south orientation). It was noted that the apparent warming in the MAB in the 1990s concentrated in the southern regions (SS1, SS2) during the winter. Atmospheric heat flux seems the likely source and needs to be investigated. Further, there is some indication that advective events present in the Gulf of Maine (GOM) have affected SNE and NYB temperature and salinity. For example, GLOBEC data indicates a shift in the basic circulation into GOM from 1 part Scotian Shelf water and 2 parts Oceanic current, to 2 parts Scotian Shelf and 1 part Oceanic water. Documentation of changes in the major inflows into the GOM is needed.

Given the extent of the variability in the data, what metrics are useful to see system-wide changes? Several data sets were examined relative to the detrended North Atlantic Oscillation (NAO) which shows significant 3-5 year variability over a strong 30 year trend. Large changes in zooplankton volume occurred over the 1970-1995 period. Volumes decreased in the early 1980s, followed by a large increase in 1985-1990 period. Plankton volume fluxes correlated with the detrended, inverse of the NAO (see chapter 4 for further details). Plankton volume and salinity anomalies may have a relationship and other covarying parameters may exist. These relationships merit further examination. Additionally, an index of cod recruitment and standing stock biomass (SSB) data correlate with the detrended, inverted NAO data. Possible relationships between the cod survival anomaly, the SSB and detrended NAO data also merit examination. Chlorophyll data is also needed to help corroborate production, particulary of the plankton (i.e., volume) and the NAO trends.

No linkage is apparent between offshore waters and the NAO events of the 1960s through the 1990s, however, the linkage between coastal water temperatures and NAO needs to be examined.

D. References

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Figure A.1. ***NAO Index***

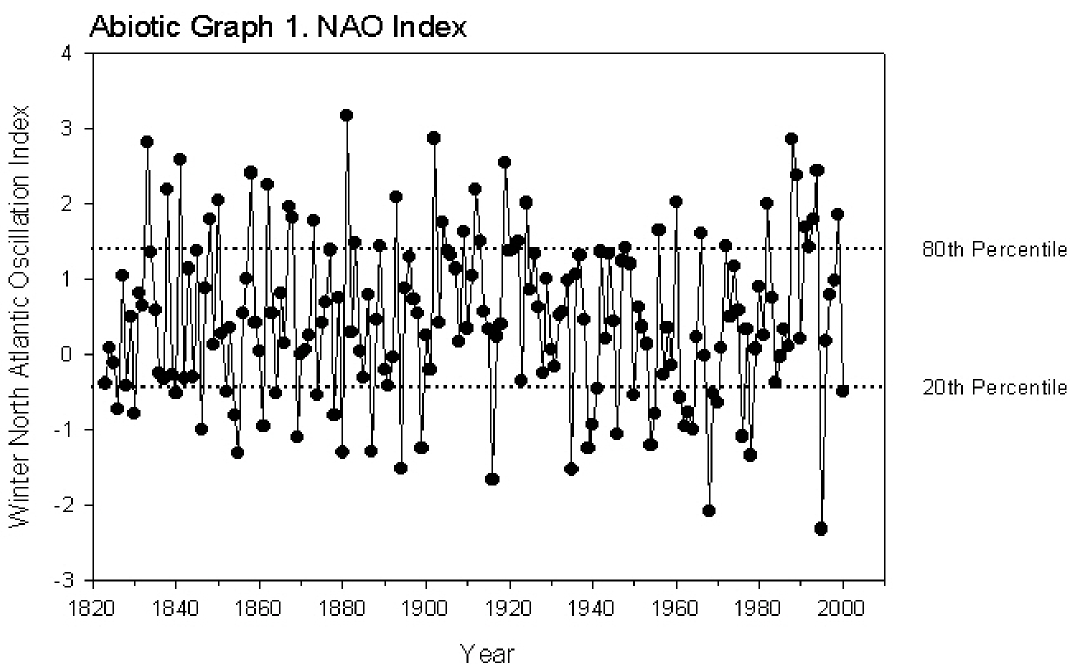


Figure A.2. ***NAO Index***

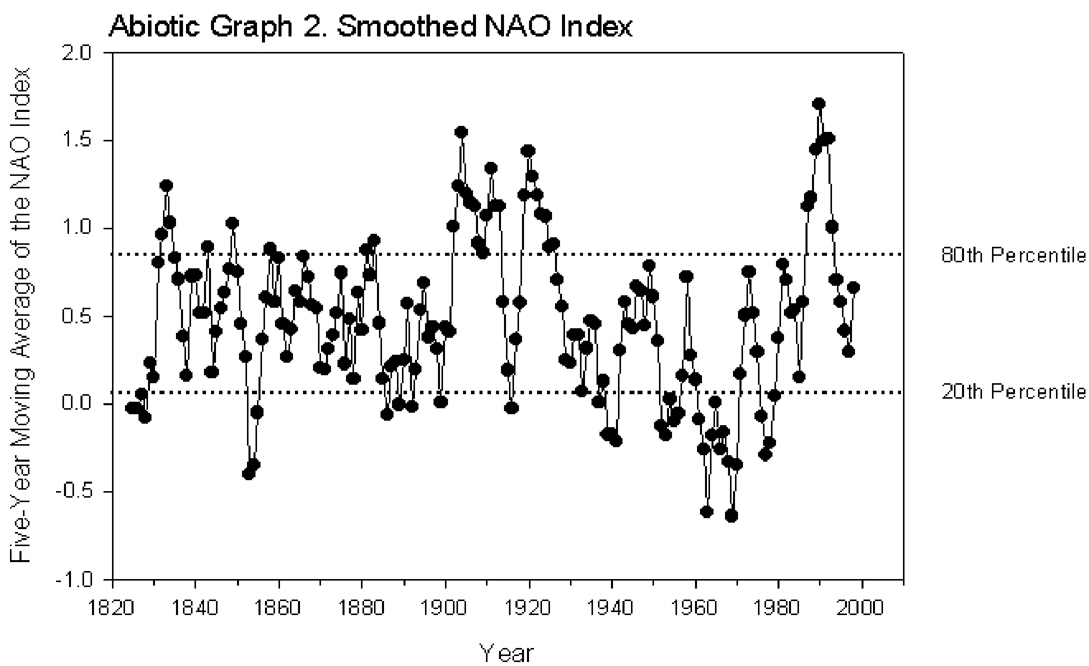
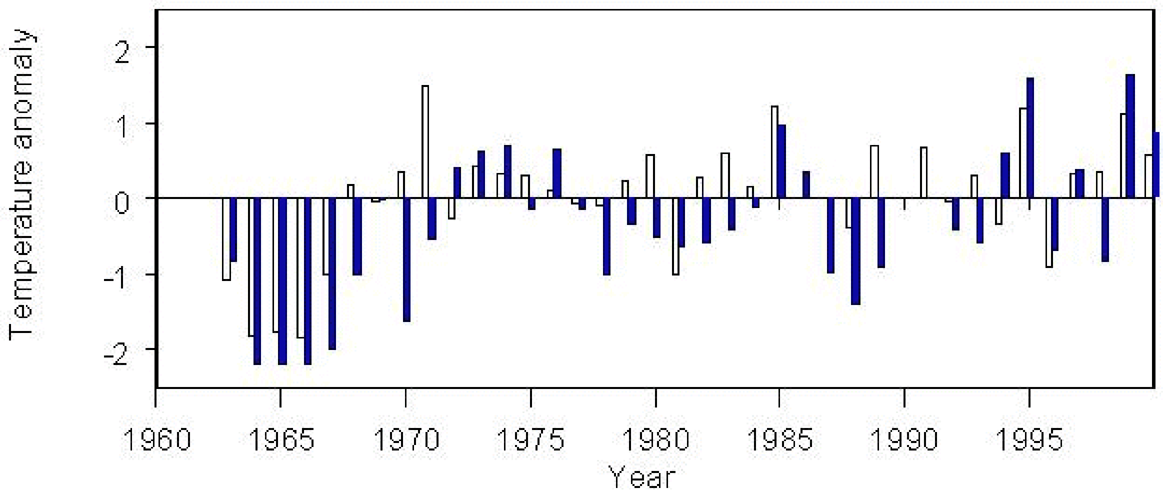


Figure A.3. ***Shelf wide Temperature anomaly***



Shelf-wide, fall surface (open bars) and bottom (filled bars) temperature anomalies:

Figure A.4a. ***MAB Volume, Salinity & Temperature anomaly***

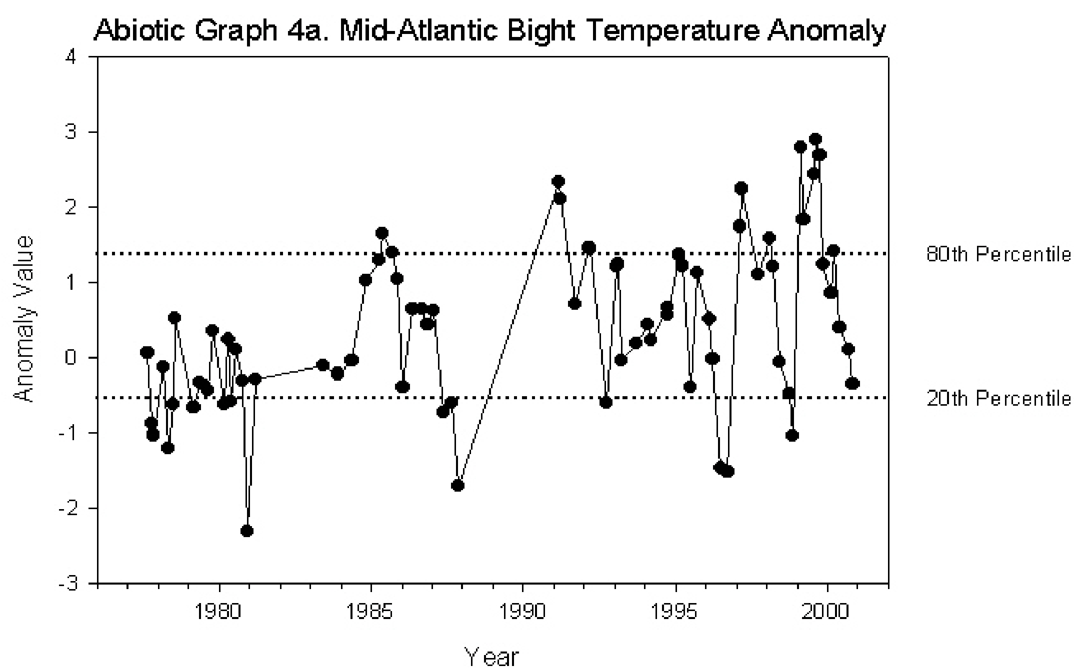


Figure A.4b. ***MAB Volume, Salinity & Temperature anomaly***

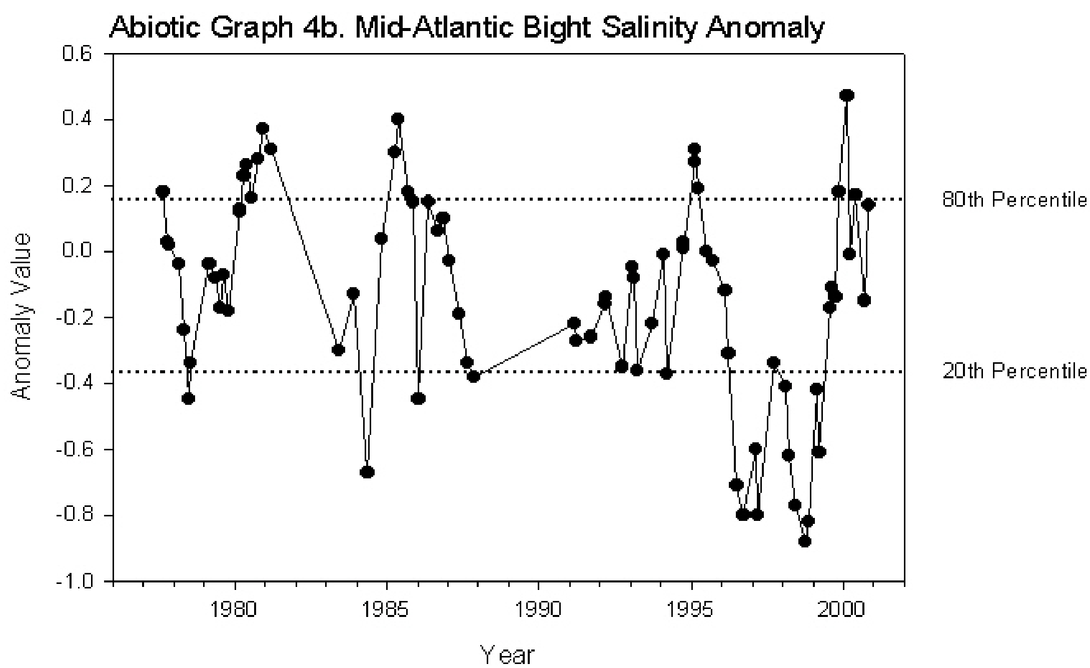


Figure A.4c. ***MAB Volume, Salinity & Temperature anomaly***

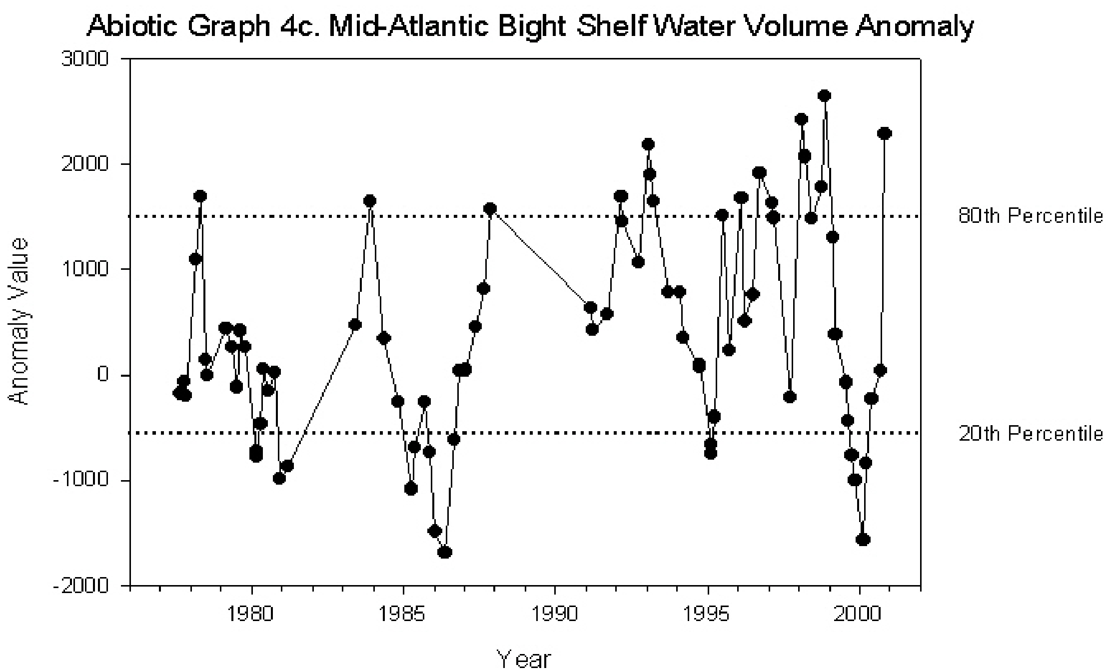


Figure A.5a. ***Surface and Bottom Temperature anomalies***

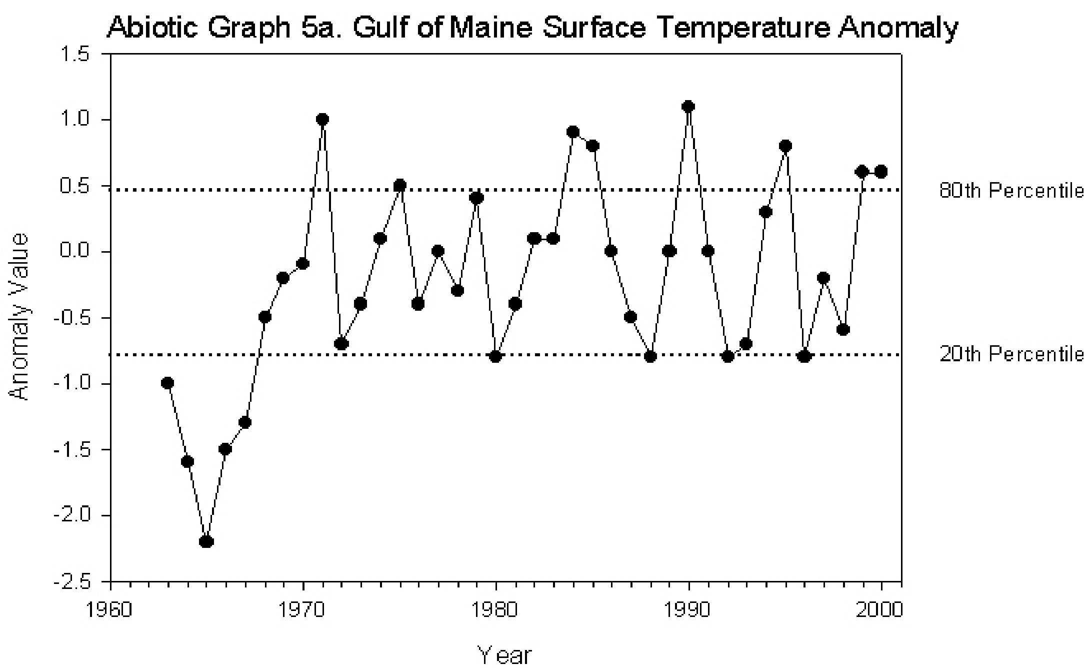


Figure A.5b. ***Surface and Bottom Temperature anomalies***

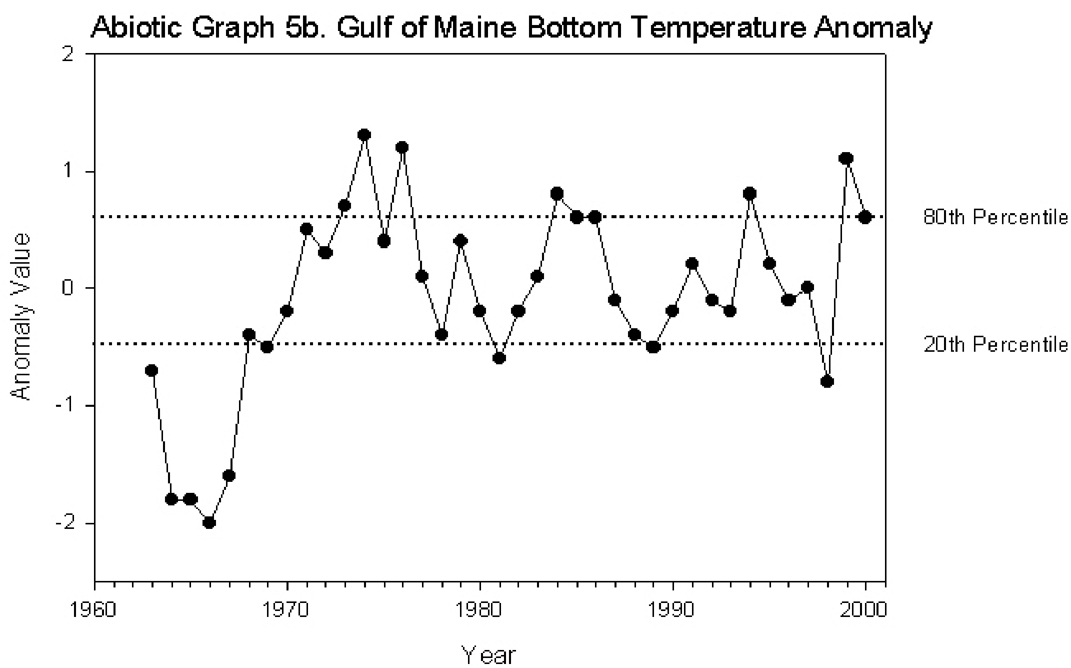


Figure A.5c. ***Surface and Bottom Temperature anomalies***

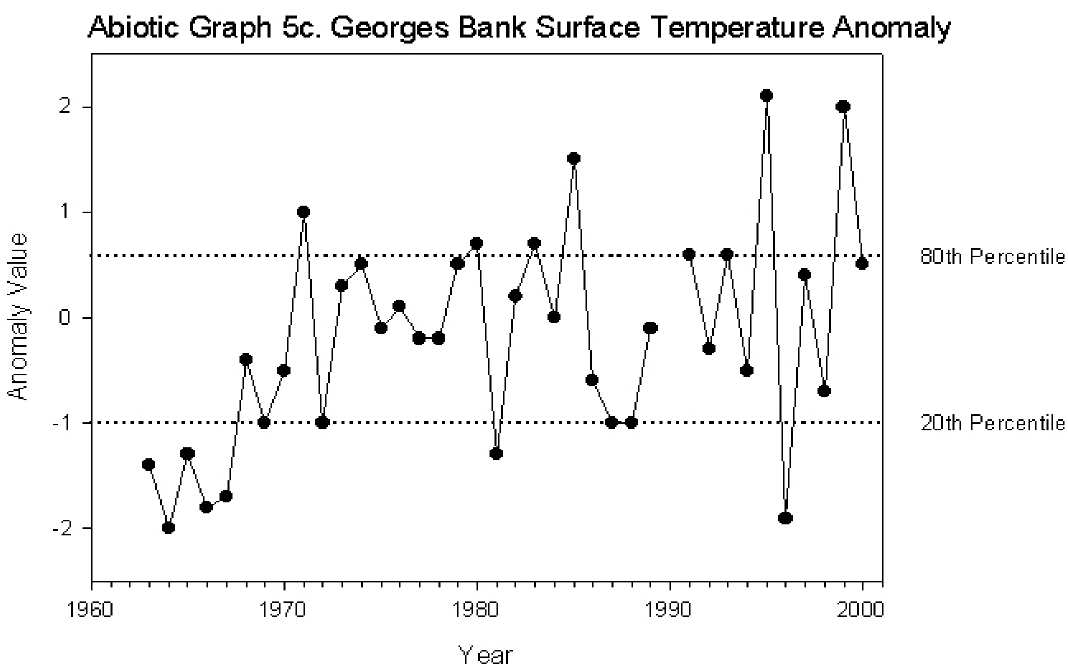


Figure A.5d. ***Surface and Bottom Temperature anomalies***

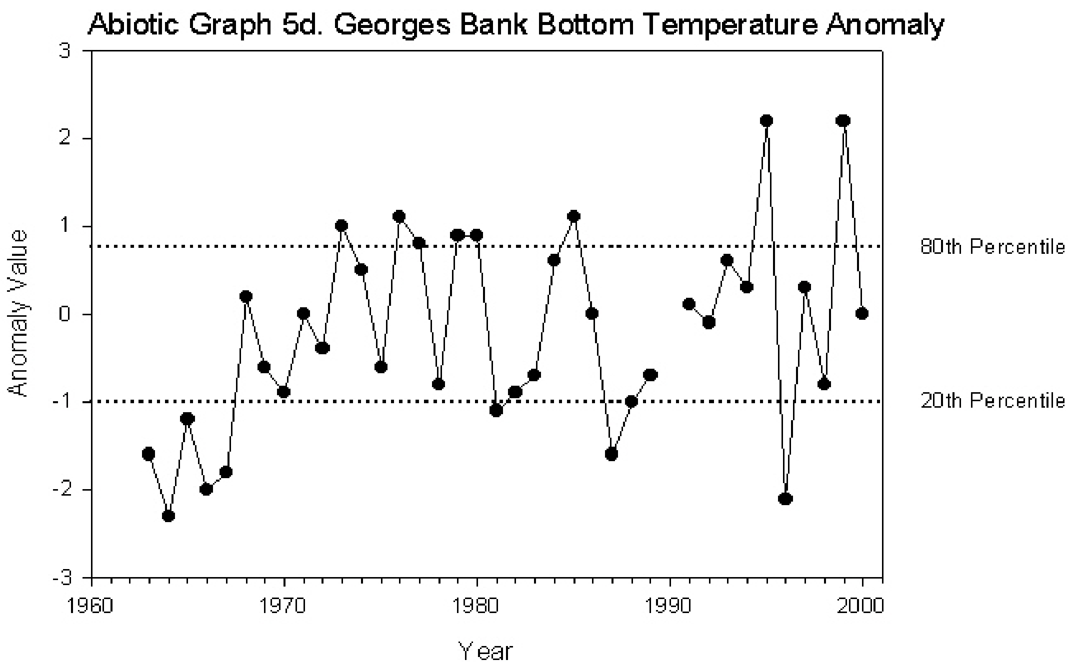


Figure A.5e. ***Surface and Bottom Temperature anomalies***

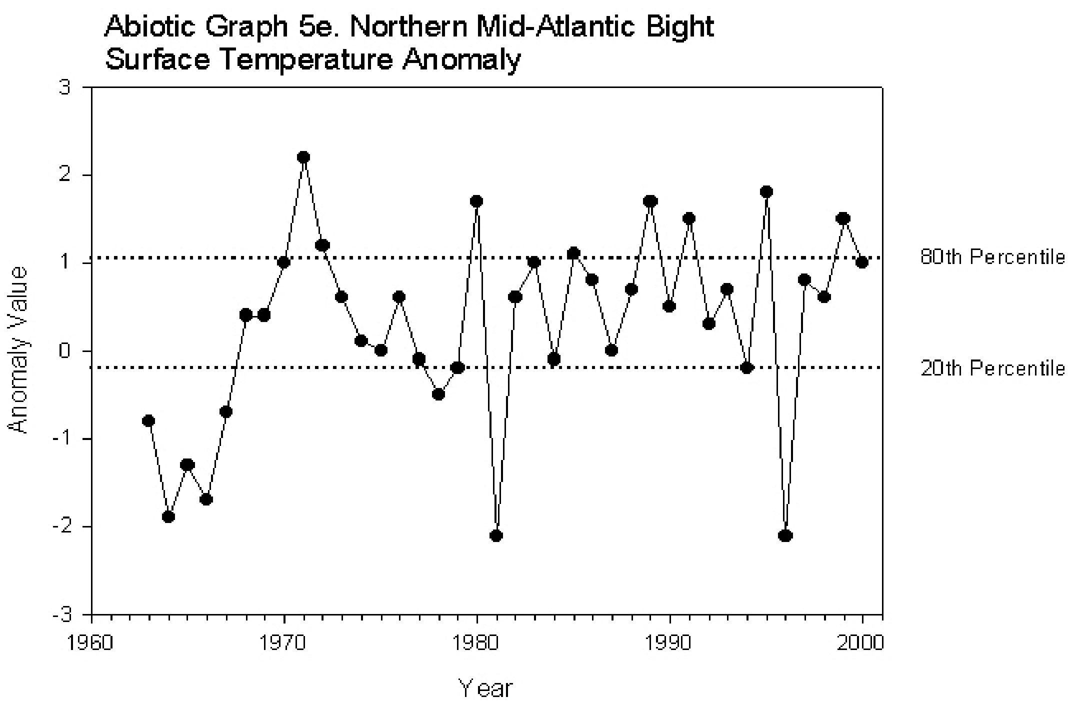


Figure A.5f. ***Surface and Bottom Temperature anomalies***

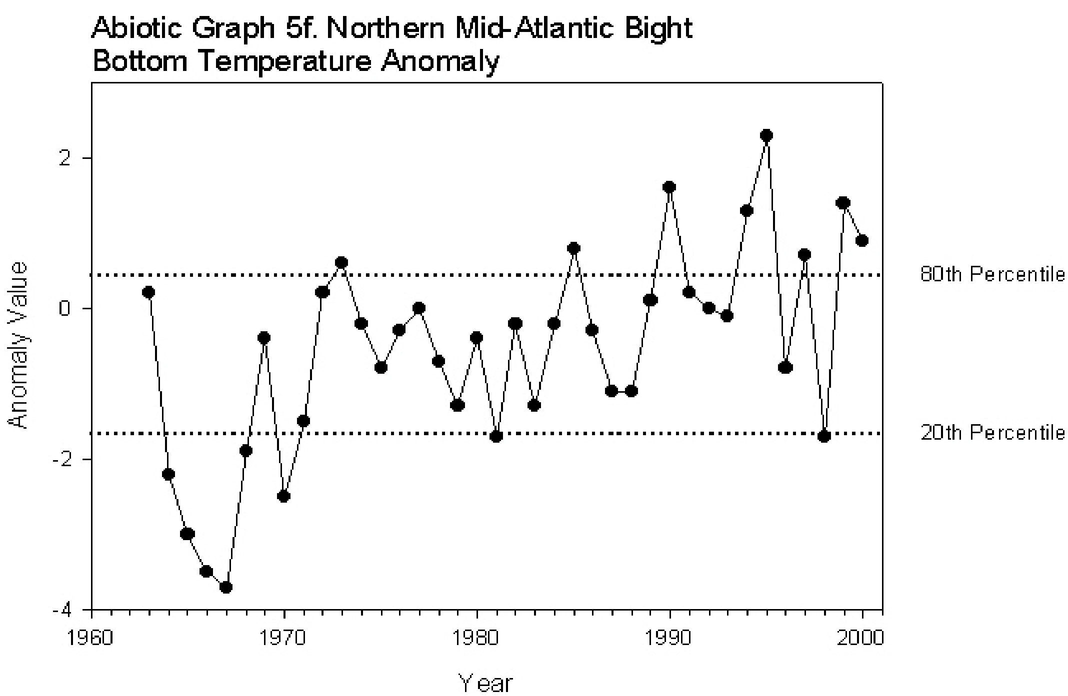


Figure A.5g. ***Surface and Bottom Temperature anomalies***

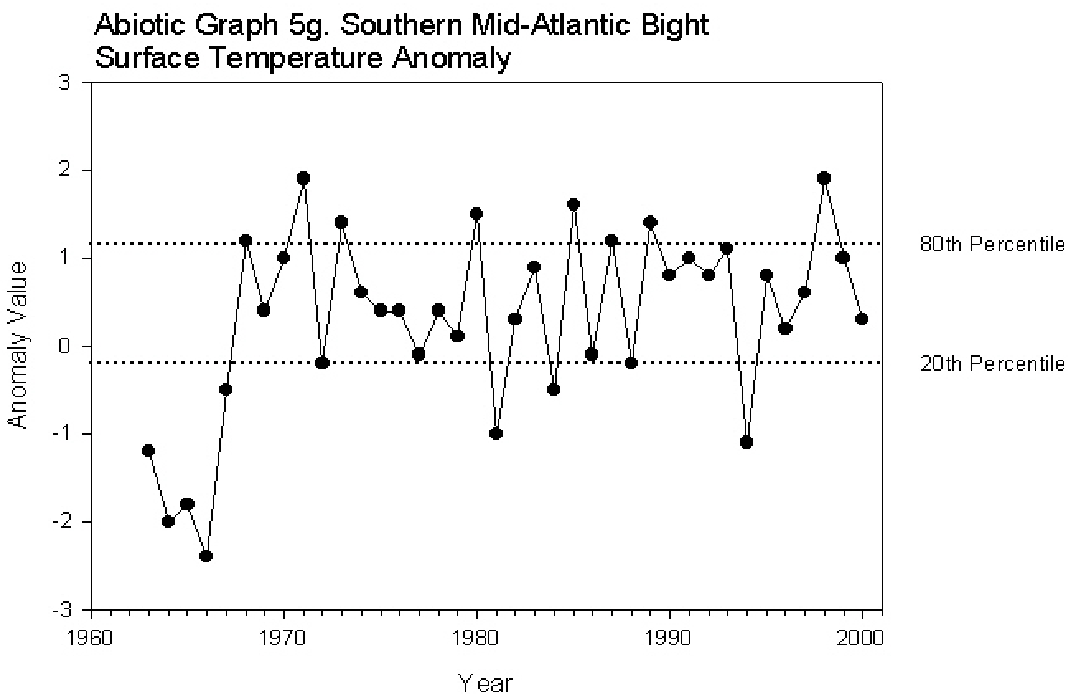


Figure A.5h. ***Surface and Bottom Temperature anomalies***

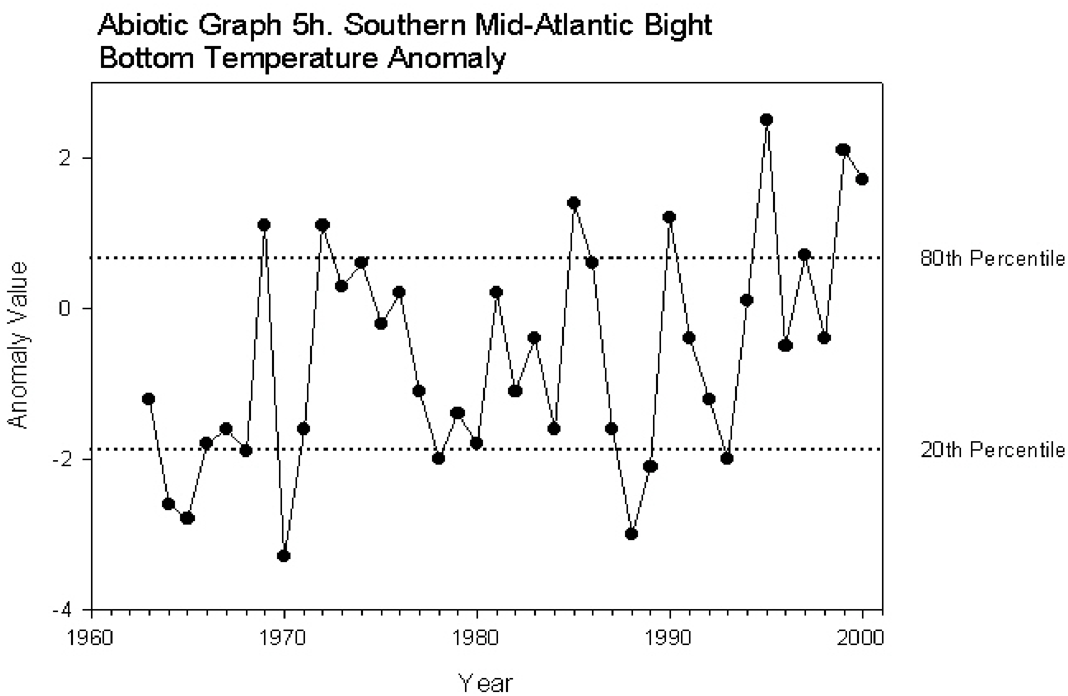
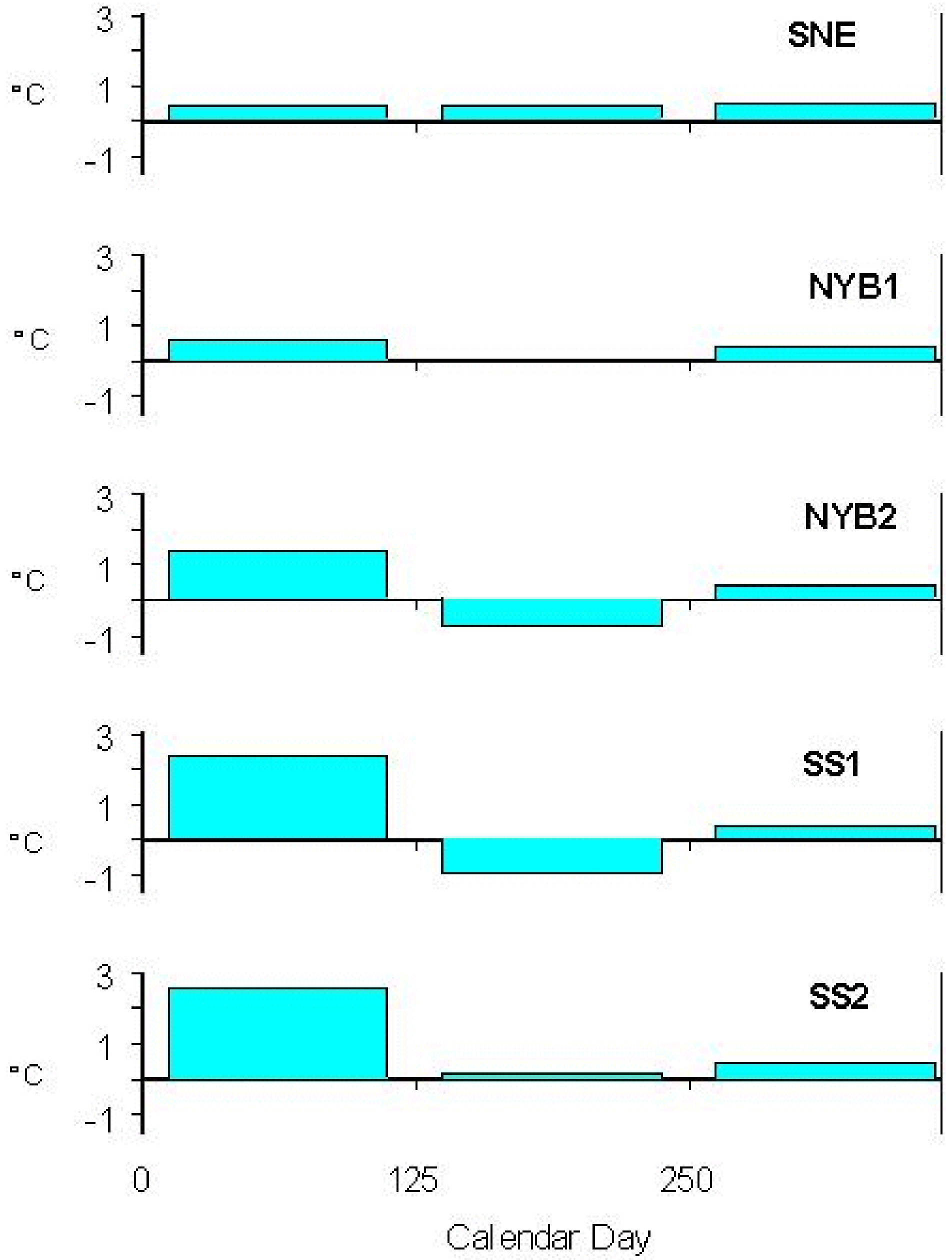
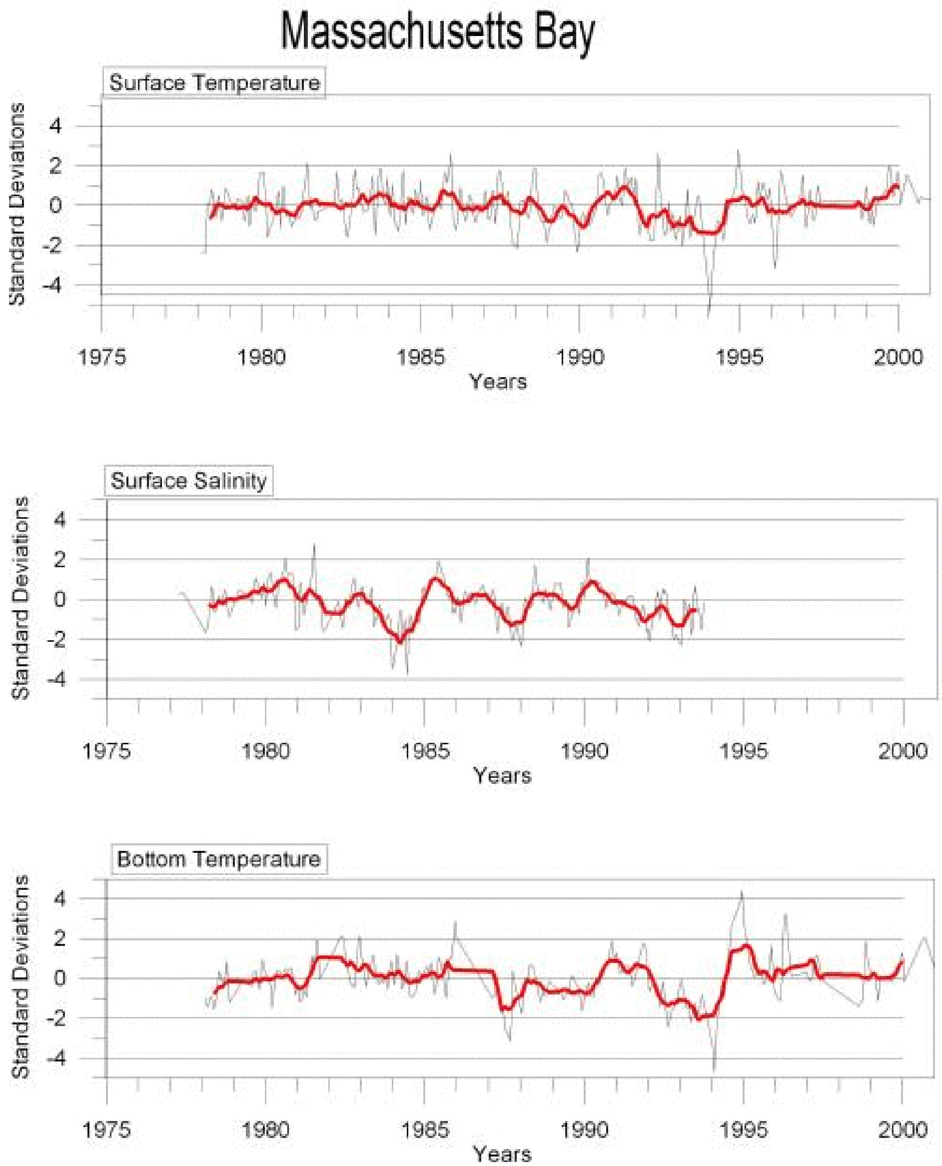


Figure A.6. ***MAB Temperature anomalies, by 5 provinces***



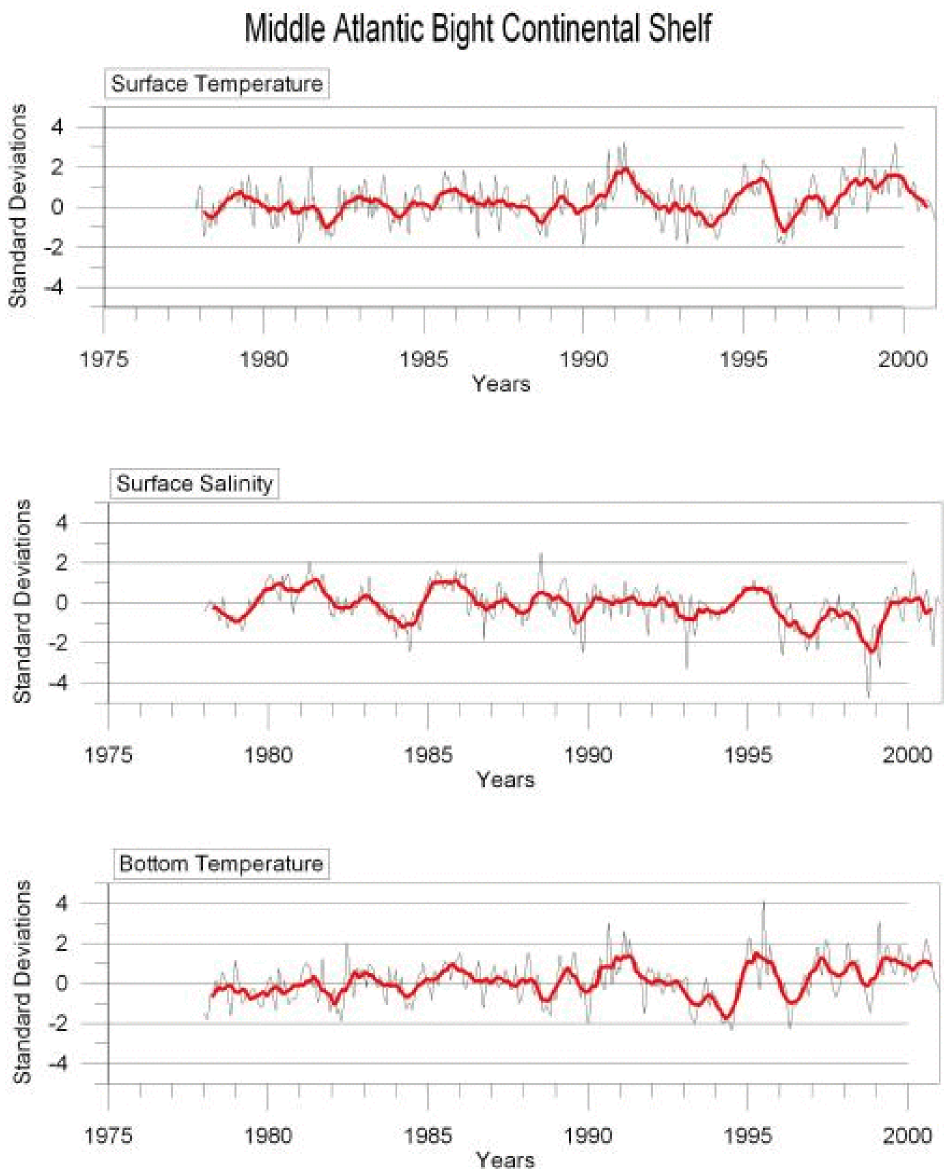
Average shelf water temperature anomaly in the 1990's relative to MARMAP (1977-1987) for five regions in the Middle Altantic Bight (from north to south), for thirds of the year.

Figure A.7. ***Massachusetts Bay Surface Temp, Surf. Salinity, Bottom Temp. Anomalies***



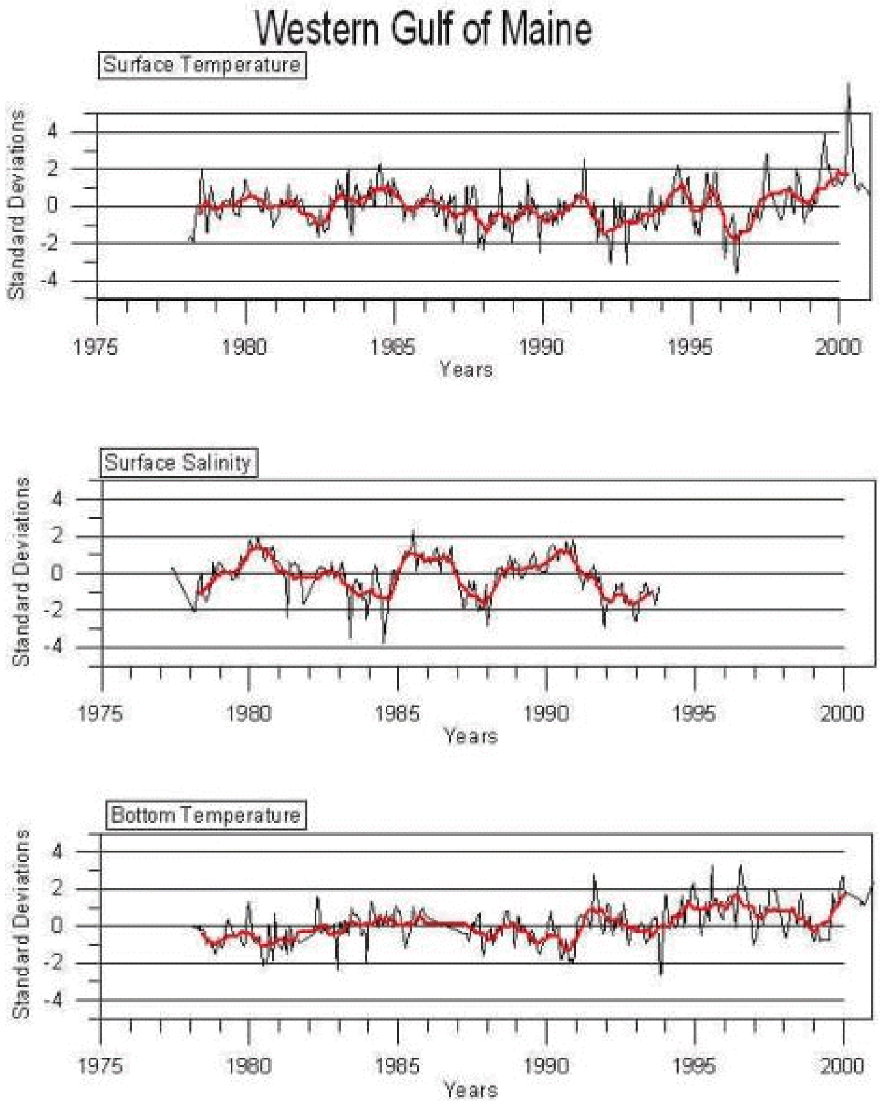
Time plots of standardized departures of surface temperature, surface salinity, and bottom temperature from 1978-1990 means, at a transect location representing Massachusetts Bay. From: MARMAP Ships of Opportunity Program

Figure A.8. ***Mid-Atlantic Bight Surface Temp, Surf. Salinity, Bottom Temp. Anomalies***



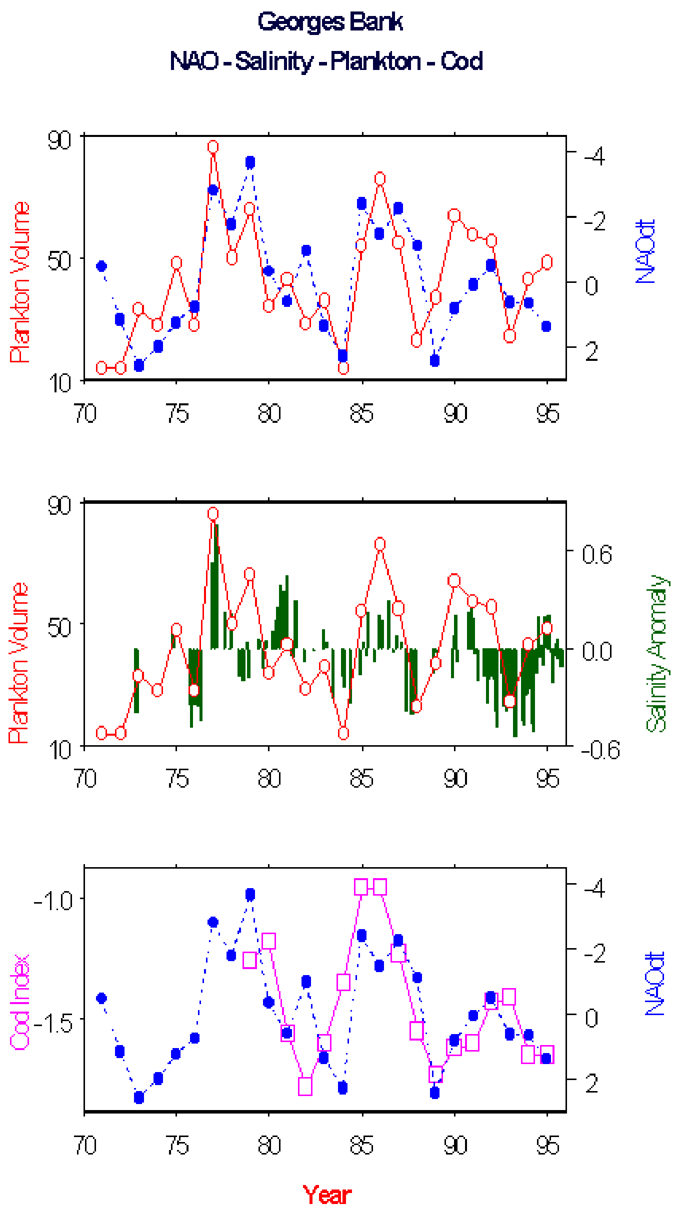
Time plots of standardized departures of surface temperature, surface salinity, and bottom temperature from 1978-1990 means, at a transect location representing the Middle Atlantic Bight continental shelf. From: MARMAP Ships of Opportunity Program.

Figure A.9. ***W. Gulf of Maine Surface Temp, Surf. Salinity, Bottom Temp. Anomalies***



Time plots of standardized departures of surface temperature, surface salinity, and bottom temperature from 1978-1990 means, at a transect location representing the western Gulf of Maine. **Fifteen month running average line fitted.**

Figure A.10. ***Relationships Among NAO, Salinity, Plankton, and Cod on Georges Bank***



IV. BIOTIC METRICS

A. Phytoplankton

1. US Northeast Continental Shelf Ecosystem, Chlorophyll-a

Time: 1977-1988

Spatial: US Northeast Shelf Ecosystem (Shelf wide)

Contributed by: J. Jossi and J.E. O'Reilly

Methodology and Data Source

These data were collected as part of the MARMAP Program. Six to twelve research vessel surveys/year undertook water column sampling of phyto-pigments in the euphotic zone (O'Reilly and Zetlin 1998).

Key Points and Major Observations

Fifty-seven thousand eighty-eight measurements were made during 78 oceanographic surveys from 1977 through 1988. Extensive horizontal, vertical, and seasonal distributions are portrayed. No time series per se has been constructed. Not much inter-annual change in chlorophyll *a* is observed.

B. Birds

We recognize that birds are an important part of this ecosystem, but few time series data are available for these species. Although there is some extant data, no one from the group provided data for this report. Certainly this is an important issue to consider for some species, and merits further examination in the future. In fact, basic questions such as "what are the trends in abundance of major species?" remain unanswered. How often do we need to sample to better answer these questions? What spatial extent and resolution do we need? What are the most cost effective methodologies?

C. Turtles

We also recognize that turtles are an important part of this ecosystem, but few time series data are available for these species. Although there is some extant data, no one from the group provided data for this report. See Palka et al. (In review) for some estimates of turtle abundance for selected years in the 1990s. Certainly this is an important issue to consider for some species, and merits further examination in the future.

D. Benthos

In general, few time series data are available for the benthos. Classic shelf-wide studies were conducted by Theroux and Wigley (1998). Other studies have covered smaller areas, and synoptic, shelf-wide information is generally lacking. However, a few components of the benthic community are surveyed regularly.

1. Georges Bank, Mid-Atlantic Bight Scallop Biomass, Landings, and Survey Indices

Time: 1962-1999 (Landings & Survey), 1980-2000 (Biomass)

Spatial: Georges Bank, Mid Atlantic Bight

Contributed by: Hart

Figures B.1-B.4

Methodology and Data Source

These data were collected from the NMFS sea scallop survey and landings database. Biomass was poststratified into open and closed areas. For further details see NEFSC (2001) and Murawski et al. (2000).

Key Points and Major Observations

Biomass was at low levels through 1994 due to increasingly severe overfishing. This resulted in highly variable landings well below optimal levels, driven primarily by sporadic recruitment events. After area closures (December 1994 in Georges Bank, April 1998 in Mid-Atlantic), there was a rapid buildup of biomass in the closed areas. The limited amount of fishing permitted in the closed areas in 1999-2000 does not appear to have substantially impacted the biomass there. Biomasses in open areas have increased recently due to effort reductions and good recruitment. Recent good recruitment on both Georges Bank and Mid-Atlantic may be related to the increased levels of spawning-stock biomass in the closed areas.

2. Sculpin abundance from fall bottom trawl survey

Time: 1963 - 1998

Spatial: Southern New England and Georges Bank

Contributed by: Link

Figure B.5

Methodology and Data Source

These data were collected as part of the NEFSC Habitat Research Program and standard bottom trawl survey. The stratified mean trawl catch per tow (Azarovitz 1981) was calculated for this species. See Link and Almeida (2002) for further details.

Key Points and Major Observations

Longhorn sculpin abundance peaked in the mid 1960s and then exhibited a relatively steady period for the first 15 years of the survey. This was followed by a period of lower abundance during the mid 1980s and an increasing trend in the 1990s. In most years sculpin abundance ranged from 10 to 20 fish per tow. The years with highest index of sculpin abundance were 1966 and 1998. Relative to the several preceding years, the index of sculpin abundance notably increased during 1966, 1987 and 1998.

3. Blue crab abundance

Time: July 1996 - October 2000 (spring, summer, and fall)

Spatial: Navesink River and Sandy Hook Bay in the mid-Atlantic region

Contributed by: Fabrizio

Figure B.6

Methodology and Data Source

These data were collected as part of the Behavioral Ecology Survey of Demersal Species in Navesink River. Three seasonal collections were made in the spring, summer, and fall beginning in the summer of 1996. Demersal species were collected by replicate tows of a 1-m beam and a 5- m otter trawl at 84 stations throughout the Navesink River and Sandy Hook Bay. Beginning in July 1998, only 24 stations were sampled throughout this system. All fish and decapod crustaceans were enumerated and environmental characteristics were measured. The data in the figure represent the mean number of blue crabs per m^2 across all stations in the Navesink River and Sandy Hook Bay (Meise and Stehlik In Press).

Key Points and Major Observations

Blue crab abundance increased in 1998-1999 in the Navesink River-Sandy Hook Bay estuarine system, but declined by 2000. These data are from a short time series with limited spatial coverage, but are important to the local estuarine dynamics.

E. Zooplankton

1. Central Gulf of Maine* Calanus finmarchicus*, c.1-4, c.5-6 anomalies

Time: 1961-1990

Spatial: Central Gulf of Maine

Contributed by: Jossi

Figure B.7 (a-b)

Methodology and Data Source

These data were collected as part of the MARMAP Ships of Opportunity Program (Benway et al. In Review; Jossi et al. In Review). Continuous Plankton Recorders were towed monthly by merchant vessels along a transect from Boston, MA to Cape Sable, NS. Zooplankton and larger phytoplankton were captured, identified and enumerated. Abundance values were gridded in time and space (distance along transect). Grids of long term medians, means and standard deviations; and single year conditions, anomalies, and standardized anomalies are produced. Grids were sliced through time at a distance representing the central Gulf of Maine in this portrayal. The portrayal also shows a smooth curve based on a 15 month running average

(Jossi and Goulet 1993; Pershing et al. 2001).

Key Points and Major Observations

A biphase pattern has been found in this, and several other of the dominant zooplankton taxa of the Gulf of Maine during the 1961-1990 period (Jossi and Goulet, 1993), and also an uptrend for the adult stages of *Calanus finmarchicus*. Also, the adult stages of this taxon have exhibited a positive (with lag) correlation with the winter North Atlantic Oscillation (Pershing,et al. 2001).

2. Anomalies of major zooplankton during spring

Time: 1977 - 1996, Spring (15 Feb- 15 May)

Spatial: Georges Bank

Contributed by: Jossi

Figure B.8

Methodology and Data Source

These data were collected as part of the MARMAP Surveys (Benway et al. In Review; Jossi et al. In Review). Zooplankton and larger phytoplankton were captured, identified and enumerated. Abundance values were gridded in time and space (distance along transect). Single year conditions, anomalies, and standardized anomalies are produced.

Key Points and Major Observations

The community composition has changed notably over time. Yet there are no apparent trends in total zooplankton abundance and no major departures from zero even though predator biomass has changed greatly during the time period.

3. Time and space conditions of* Centropagus typicus *across the continental shelf

Time: 1976 - 1990, averaged

Spatial: transect from New York to Bermuda

Contributed by: Jossi

Figure B.9

Methodology and Data Source

These data were collected as part of the MARMAP Ships of Opportunity Program (Benway et al. In Review; Jossi et al. In Review). Continuous Plankton Recorders were towed monthly by merchant vessels along a transect from New York to Bermuda. Zooplankton and larger phytoplankton were captured, identified and enumerated. Abundance values were gridded in time and space (distance along transect). Grids of long term medians, means and standard deviations; and single year conditions, anomalies, and standardized anomalies are produced.

Key Points and Major Observations

An impressive color figure captures seasonal and local spatial dynamics well, although this is not a time series per se.

4.* Calanus *abundance by day of year over time

Time: 1961 - 1998

Spatial: transect from Boston, Mass. to Cape Sable

Contributed by: Jossi

Figure B.10

Methodology and Data Source

These data were collected as part of the MARMAP Ships of Opportunity Program (Benway et al. In Review; Jossi et al. In Review). Continuous Plankton Recorders were towed monthly by merchant vessels along a transect from Boston, MA to Cape Sable, NS. Zooplankton and larger phytoplankton were captured, identified and enumerated. Abundance values were gridded in time and space (distance along transect), and in this case, gridded in time (years) *vs* time (days of year). This portrayal shows changes of seasonality for the Gulf of Maine as a whole during the 38 year time span.

Key Points and Major Observations

During the mid 1980s, *Calanus finmarchicus* shows up later and leaves earlier. In the early1990s there is an even earlier appearance of this species. Can these timing changes be related to the changing oceanographic conditions over this time period?

5: The overall zooplankton biomass and abundance trends of two dominant copepods:

Calanus finmarchicus *and* Centropages typicus

Time: 1977 - 2000

Spatial: Georges Bank and Gulf of Maine

Contributed by: Kane

Figures B.11 and B.12

Methodology and Data Source

These data were collected as part of the MARMAP Surveys (Benway et al. In Review; Jossi et al. In Review). Zooplankton samples were collected at approximately bimonthly intervals throughout the region with a 0.333-mm mesh net fitted on one side of a 61-cm bongo frame. Biomass was measured by displacement volume and individual species were sorted and counted from sub samples. Data in the figures represent ranked departures from the time series monthly means with a fourth order polynomial fit to the data. See Kane (1993), Sherman et al. (1998), and Kane (1999) for further details.

Key Points and Major Observations

Zooplankton trends in both regions were similar. Biomass was usually high in the late seventies, low throughout most of the eighties, and highly variable during the 1990s. The biomass trend line on Georges Bank during the 1990s is higher because of high values recorded in 1989 and 1990, years where budget constraints prevented sampling in the GOM. *Calanus finmarchicus* abundance was high in the late seventies and highly variable during the past two decades with no persistent long-term trend. *Centropages typicus* density was high from 1978-82, low throughout the remainder of the 1980s, and above average during the past decade.

6. Total Zooplankton Biomass

Time: 1977-2000

Spatial: Shelf wide

Contributed by: Kane

Figure B.13

Methodology and Data Source

These data were collected as part of the MARMAP Surveys (Benway et al. In Review; Jossi et al. In Review). Zooplankton samples were collected at approximately bimonthly intervals throughout the region with a 0.333-mm mesh net fitted on one side of a 61-cm bongo frame. Biomass was measured by displacement volume and individual species were sorted and counted from sub samples. Data in the figures represent ranked departures from the time series monthly means with a fourth order polynomial fit to the data. See Kane (1993), Sherman et al. (1998), and Kane (1999) for further details.

Key Points and Major Observations

Biomass was generally higher in the late 1970s, with no persistant long term trend during the past two decades. There was a lot of variability in the data. Patterns are similar in each of the four main subregions.

F. Fish and Squids

For the majority of these organisms, we refer the reader to NEFSC (1998a, 1998b, 1998c, 2000a, 2000b, 2000c, 2001). These documents contain individual species stock assessments and annual reports on the status of the major or commerically valuable species.

1. Relative abundance of northeast species groups (groundfish, pelagics, elasmobranchs, others) from combined fall and spring bottom trawl surveys

Time: 1963 - 1999

Spatial: Shelf wide

Contributed by: NEFSC

Figure B.14 (a-d)

Methodology and Data Source

These data were collected as part of the NEFSC Bottom Trawl Survey (Azarovitz 1981; NEFC 1988). Species were aggregated as principal groundfish, other groundfish, principal pelagics, and elasmobranchs. A stratified mean biomass per tow was calculated and smoothed over the time series.

Key Points and Major Observations

The abundance of principal groundfish declined through the mid 1970s, increased slightly in the late 1970s and early 1980s, and declined thereafter, remaining at low levels through the 1990s. The abundance of pelagic fishes declined in the 1970s and increased substantially and continuously thereafter. Elasmobranch abundance increased from the 1960s through the 1990s, then declined moderately in the late 1990s. The abundance of other groundfish has fluctuated without trend. These observations suggest a shift in community structure and food web dominance.

2. Principal groundfish biomass for Georges Bank from autumn bottom trawl survey

Time: 1963 - 1999

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.15

Methodology and Data Source

The principal groundfish index is the sum of indices of 12 principal (exploited) groundfish on Georges Bank. These species include Atlantic cod (*Gadus morhua*), haddock (*Melanogrammus aeglefinus*), redfish (*Sebastes fasciatus*), silver hake (*Merluccius bilinearis*), red hake (*Urophyscis chuss*), pollock (*Pollachius virens*), yellowtail flounder (*Limanda ferruginea*), summer flounder (*Paralichthys dentatus*), American plaice (*Hippoglossoides platessoides*), witch flounder (*Glyptocephalus cynoglosses*), winter flounder (*Pseudopleuronectes americanus*), and windowpane flounder (*Scophthalmus aquosus*). The individual indices are stratified mean weight per tow during autumn, calculated with survey gear adjustment factors applied where appropriate using NEFSC offshore survey strata 9-23 and 25. See Brodziak and Link (2002) and Azarovitz (1981) for further details.

Key Points and Major Observations

A large decline in principal groundfish occurred during 1960s and early 1970s. A moderate increase occurred during the late-1970s and early 1980s. Principal groundfish abundance declined through the 1990s, although recently there has been a moderate increase.

3. Elasmobranch biomass for Georges Bank from autumn bottom trawl survey

Time: 1968 - 2000

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.16

Methodology and Data Source

The elasmobranch index is the sum of indices of 6 primary elasmobranchs on Georges

Bank. These species include spiny dogfish (*Squalus acanthius*), barndoor skate (*Raja laevis*), thorny skate (*Raja radiata*), smooth skate (*Raja senta*), winter skate (*Raja ocellata*), and little skate (*Raja erinacea*). The individual indices are stratified mean weight per tow during spring, calculated with survey gear adjustment factors applied where appropriate using NEFSC offshore survey strata 9-23 and 25. See Brodziak and Link (2002) and Azarovitz (1981) for further details.

Key Points and Major Observations

Elasmobranch biomass was low in the 1970s. Elasmobranch biomass increased to high values in the 1980s and early1990s. Elasmobranch biomass has decreased in the late1990s.

4. Principal pelagics biomass estimates from recent assessments

Time: 1967 - 1994

Spatial: entire range of population in the northwest Atlantic (shelf wide)

Contributed by: Brodziak

Figure B.17

Methodology and Data Source

These data were derived from the NEFSC assessments of pelagics species. Age-structured assessments using sequential population analysis tuned to NEFSC survey abundance-at-age indices were used. See Brodziak and Link (2002) and NEFSC (1998a) for further details.

Key Points and Major Observations

The principal pelagics (Altantic herring *Clupea harengus* and Atlantic mackerel *Scomber scombrus*) are migratory resources that were heavily fished by distant water fleets in the 1960s-1970s. Abundance of principal pelagics was high (or moderate) in the early-1970s and declined to record lows in the 1970s and early-1980s. Abundance was high and increasing in the late-1980s through the 1990s.

5. Cephalapod biomass for Georges Bank from fall bottom trawl survey

Time: 1967 - 1999

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.18

Methodology and Data Source

The cephalopod biomass index is the sum of indices of two principal (exploited) cephalopods, long-finned squid (*Loligo pealeii*) and northern short-finned squid (*Illex illecebrosus*), along with other squid and octopuses on Georges Bank. The individual indices are stratified mean weight per tow during autumn, calculated with survey gear adjustment factors applied where appropriate using NEFSC offshore survey strata 9-23 and 25. See Brodziak and Link (2002) and Azarovitz (1981) for further details.

Key Points and Major Observations

Cephalopods are short-lived (lifespan< 1 year) and are common prey for many species. Distribution of the two primary squids on Georges Bank depends on seasonal changes in water temperatures. Cephalopod abundance increased during the late-1960s to late-1970s, declined to the mid-1980s, and increased in the late-1980s. Abundance declined during the early 1990s and has increased moderately since 1996.

6. Frequency of occurrence of parasitic nematodes in all predators

Time: 1973 - 1998 in five year blocks

Spatial: Shelf wide

Contributed by: Link

Figure B.19

Methodology and Data Source

These data were derived from the NEFSC Food Habits Database. Live nematodes observed in examined stomachs were noted. See Link and Almeida (2000) for further details.

Key Points and Major Observations

There was a methodological shift between 1980 and 1981, so the apparent trend may be misleading. Otherwise nematode occurrence may provide an index of density dependent health in fish.

7. Winter flounder collected by beam and otter trawls

Time: July 1996 - October 2000 (spring, summer, and fall)

Spatial: Navesink River and Sandy Hook Bay in the mid-Atlantic region

Contributed by: Fabrizio

Figure B.20

Methodology and Data Source

These data were collected in the Behavioral Ecology Survey of Demersal Species. Three seasonal collections were made in the spring, summer, and fall beginning in the summer of 1996. Demersal species were collected by replicate tows of a 1-m beam and a 5- m otter trawl at 84 stations throughout the Navesink River and Sandy Hook Bay. Beginning in July 1998, only 24 stations were sampled throughout this system. All fish and decapod crustaceans were enumerated and environmental characteristics were measured. The data in the figure represent the mean number of winter flounder per m^2 across all stations in the Navesink River and Sandy Hook Bay. See Stehlik and Meise (2000) and Stoner et al. (2001) for further details.

Key Points and Major Observations

Beam trawls captured newly settled winter flounder, and generally not older stages. As indicated by the beam trawl samples, young-of-the-year winter flounder abundance was high in the spring of 1999. These data are from a short time series with limited spatial coverage, but are important to the local estuarine dynamics.

8. Haddock and cod % maturity for ages 1 and 2

Time: 1963 - 1997 in five year blocks (haddock) and 1978 - 1997 in four year blocks (cod)

Spatial: Georges Bank

Contributed by: NEFSC SARCs

Figure B.21

Methodology and Data Source

These data are from the NEFSC Age Database (SVBIO) collected as part of the bottom trawl survey. The particular analyses for these species can be found in NEFSC (1998b, 1998c, 2000a, 2000b, 2000c, 2001).

Key Points and Major Observations

Haddock seem to show an increase in early maturity over time. How do changes in maturity reflect ecosystem level effects?

9. Cod survival ratio anomaly

Time: 1978 - 1998

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.22

Methodology and Data Source

The cod survival ratio anomaly measures the difference between the observed value of cod recruitment per unit of spawning biomass (survival ratio index) and its predicted value from a fitted Beverton-Holt stock-recruitment curve. Higher anomaly values are associated with more favorable recruitment conditions. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

The Georges Bank cod survival ratio anomaly has no apparent trend during 1978-1998, although anomaly values were negative in the late 1980s-early 1990s and have been more positive since 1995. Georges Bank cod recruitment has been low in recent years and this data suggests that this is not primarily due to adverse environmental conditions. Survival ratio anomaly measures deviation of recruits per spawner from a spawner recruit relationship.

10. Haddock survival ratio anomaly

Time: 1931 - 1998

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.23

Methodology and Data Source

The haddock survival ratio anomaly measures the difference between the observed value of haddock recruitment per unit of spawning biomass (survival ratio index) and its predicted value from a fitted Beverton-Holt stock-recruitment curve. Lower anomaly values are associated with less favorable recruitment conditions. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

Georges Bank haddock survival ratio anomalies appear to be higher during the 1930s-early 1960s than during the late1960s-1990. The two largest anomalies correspond to the 1963 and 1975 year classes which were very large based on assessment results (i.e., the two “super year classes” are apparent). Survival ratio anomaly measures deviation of recruits per spawner from a spawner recruit relationship.

11. Yellowtail flounder survival ratio anomaly

Time: 1973 - 1997

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.24

Methodology and Data Source

The yellowtail survival ratio anomaly measures the difference between the observed value of yellowtail flounder recruitment per unit of spawning biomass (survival ratio index) and its predicted value from a fitted Beverton-Holt stock-recruitment curve. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

There appears to be an increasing trend in the survival ratio anomaly since the mid-1980s. Since area II was closed on Georges Bank in 1994, the survival ratio anomalies have been relatively high. Survival ratio anomalies for Georges Bank yellowtail flounder appear to be more variable than for cod or haddock. Survival ratio anomaly measures deviation of recruits per spawner from a spawner recruit relationship.

G. Mammals

1. Several marine mammal trends

Time: Various years in the 1980s, 90s

Spatial: Shelf wide

Contributed by: Palka, Smith

Table 4.1

Methodology and Data Sources

Abundance of harbor seals were estimated as the total count of hauled out animals that were estimated from aerial photos of animals hauled out during the pupping season on the New England coast (Gilbert and Guldager 1998). This abundance is considered a minimum estimate because it was not corrected for animals in the water or outside the survey area.

Data for all other species were collected during sighting line transect surveys conducted by planes (1982, 1995, 1998, and 1999) and/or ships (1991-1999). Shipboard data were collected using the two independent sighting team procedure and were analyzed using the product integral or modified direct duplicate methods (Palka 1995). These estimates were corrected for *g(0)*, the probability of detecting a group on the track line and, if applicable, also for school size-bias. Standard aerial sighting procedures with two bubble windows and one belly window observer were used during the aerial surveys. An estimate of *g(0)* was not made for the aerial portion of the surveys, except for harbor porpoises from surveys conducted after 1990. For a brief overview of all survey results, see CETAP (1982), Smith et al. (1993), Palka (1996), Palka (2000), Waring et al. (2000), Mullin (In review) and Palka et al. (In review).

Key Points and Major Observations

These surveys were conducted in different areas within the US and Canadian Northwest Atlantic Ocean, thus, it is not possible to directly compare the reported numbers. Most of these estimates are negatively biased due to not accounting for dive times, ship reaction, and animals outside of the surveyed area. These biases vary by species. Estimates from1998/1999 are generally the largest, and the best recent estimates, because the surveys covered waters from

Florida to the Gulf of St. Lawrence, the largest portion of the animal's habitat that was ever covered.

H. Aggregate

1. Total biomass from both fall and spring bottom trawl surveys

Time: 1963 - 2000

Spatial: Shelf wide

Contributed by: Link

Figure B.25 (a-b)

Methodology and Data Source

These data were collected as part of the NEFSC Bottom Trawl Survey (Azarovitz 1981; NEFC 1988). Biomass of all net-caught organisms was aggregated irrespective of species, and a stratified mean biomass per tow was calculated over the time series. Both a mean per tow and minimum swept area estimate of total biomass were calculated.

Key Points and Major Observations

There is no apparent trend in total biomass from the mid 1960s to 2000s. The may reflect an overall system carrying capacity. The implication is that if we want to simulataneously rebuild/restore all major groups, then other components of the ecosystem will have to decline. Can fluctuations in total biomass be linked to the physical environment? This raises the question of examining standing stock vs productivity (changes in trophic transfer) of the different component species. The bottom trawl is not highly selective for pelagics, jellyfish, plankton, etc., and no corrections for selectivity were made. The jump in biomass during the late 1960s could be due to adding the spring survey in 1968.

2. Mean length of all species collected in fall and spring bottom trawl

Time: 1963 - 2000

Spatial: Georges Bank

Contributed by: Link

Figure B.26

Methodology and Data Source

These data were collected as part of the NEFSC Bottom Trawl Survey (Azarovitz 1981; NEFC 1988). Organisms were aggregated irrespective of species, and a stratified mean length for each year was calculated over the time series.

Key Points and Major Observations

Lengths were lower through the mid 1970s, and longer in the late 1970s through early 1990s. Lengths were again shorter in the mid to late 1990s. Does this infer regime shifts, or could it just be the effect of dogfish and skates? The peak length corresponds to the period when herring and other pelagics were low in abundance.

3. Abundance of various guilds in fall and spring bottom trawl surveys

Time: 1963 - 2000

Spatial: Shelf wide

Contributed by: Link

Figure B.27 (a-l)

Methodology and Data Source

These data were collected as part of the NEFSC Bottom Trawl Survey (Azarovitz 1981; NEFC 1988). Species were aggregated into appropriate guilds (Garrison and Link 2000), and a stratified mean biomass per tow was calculated and smoothed over the time series. Both a mean per tow and minimum swept area estimate of total biomass were calculated.

Key Points and Major Observations

These results are similar to other graphs of grouped biomass. Do these better convey information better than groupings by taxonomy? Guilds may be an useful approach, and certainly provide a slightly different picture of fish community dynamics than the taxonomic groupings.

I. Community Indices

1. Gulf of Maine total species diversity from bottom trawl survey

Time: 1963 - 2000

Spatial: Gulf of Maine

Contributed by: Brodziak

Figure B.28

Methodology and Data Source

Total species diversity was indexed by the average number of species per haul during the autumn bottom trawl survey in Gulf of Maine offshore strata. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

This diversity index has an increasing trend since late 1980s. The most recent index value is the highest in time series. This measure may have been impacted by decisions regarding recording of species during trawl survey cruises.

2. Gulf of Maine abundant species diversity from bottom trawl survey

Time: 1963 - 2000

Spatial: Gulf of Maine

Contributed by: Brodziak

Figure B.29

Methodology and Data Source

Abundant species diversity was indexed by the average number of abundant species (N1) per haul during the autumn bottom trawl survey in Gulf of Maine offshore strata. N1 was computed as the $N1=e^H$, where H was Shannon's diversity index evaluated in terms of the biomass proportion within a trawl sample. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

This diversity index peaked in the early 1980s. This index provides a measure of species dominance.

3. Gulf of Maine species evenness from bottom trawl survey

Time: 1963 - 2000

Spatial: Gulf of Maine

Contributed by: Brodziak

Figure B.30

Methodology and Data Source

This is Hill's modified evenness index (see for example, Ludwig and Reynolds 1988). Species evenness was indexed by the average of the ratio (N2-1)/(N1-1) during the autumn bottom trawl survey in Gulf of Maine offshore strata. N2 was computed as the inverse of Simpson's diversity index, evaluated in terms of the biomass proportion within a trawl sample. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

Species evenness has a decreasing trend since the early 1980s. Current evenness values are the lowest in the time series. The decreasing trend in evenness may be due to the abundance of large skates in some areas of the Gulf of Maine.

4. Georges Bank total species diversity from bottom trawl survey

Time: 1963 - 2000

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.31

Methodology and Data Source

Total species diversity was indexed by the average number of species per haul during the autumn bottom trawl survey in Georges Bank strata. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

This diversity index appears to trend up and down throughout the observed time series. Total species diversity on Georges Bank has trended upward since the early 1990s after declining to a time series low during the 1980s. This measure may have been impacted by decisions regarding recording of species during trawl survey cruises.

5. Georges Bank abundant species diversity from bottom trawl surveys

Time: 1963 - 2000

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.32

Methodology and Data Source

Abundant species diversity was indexed by the average number of abundant species (N1) per haul during the autumn bottom trawl survey in Georges Bank strata. N1 was computed as the $N1=e^H$, where H was Shannon's diversity index evaluated in terms of the biomass proportion within a trawl sample. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

This species dominance index was higher during the 1960s-1970s than during the 1980s.

In recent years, abundant species diversity has exhibited an increasing trend. This metric is a measure of dominance.

6. Georges Bank species evenness from bottom trawl surveys

Time: 1963 - 2000

Spatial: Georges Bank

Contributed by: Brodziak

Figure B.33

Methodology and Data Source

This is Hill's modified evenness index (see for example, Ludwig and Reynolds 1988). Species evenness was indexed by the average of the ratio (N2-1)/(N1-1) during the autumn bottom trawl survey in Georges Bank strata. N2 was computed as the inverse of Simpson's diversity index, evaluated in terms of the biomass proportion within a trawl sample. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

Species evenness on Georges Bank peaked in the early 1970s. This index steadily decreased during 1975-1990 and has only increased a small amount in recent years.

7. Mid-Atlantic Bight total species diversity from bottom trawl surveys

Time: 1963 - 2000

Spatial: Mid-Atlantic Bight

Contributed by: Brodziak

Figure B.34

Methodology and Data Source

Total species diversity was indexed by the average number of species per haul during the autumn bottom trawl survey in Mid-Atlantic Bight offshore strata. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

This diversity index has no apparent trend.

8. Mid-Atlantic Bight Abundant species diversity from bottom trawl surveys

Time: 1963 - 2000

Spatial: Mid-Atlantic Bight

Contributed by: Brodziak

Figure B.35

Methodology and Data Source

Abundant species diversity was indexed by the average number of abundant species (N1) per haul during the autumn bottom trawl survey in Gulf of Maine offshore strata. N1 was computed as the $N1=e^{H}$, where H was Shannon's diversity index evaluated in terms of the biomass proportion within a trawl sample. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

This measure of species dominance has no apparent trend.

9. Mid-Atlantic Bight Species evenness from bottom trawl survey

Time: 1963 - 2000

Spatial: Mid-Atlantic Bight

Contributed by: Brodziak

Figure B.36

Methodology and Data Source

This is Hill's modified evenness index (see for example, Ludwig and Reynolds 1988). Species evenness was indexed by the average of the ratio (N2-1)/(N1-1) during the autumn bottom trawl survey in Gulf of Maine offshore strata. N2 was computed as the inverse of Simpson's diversity index, evaluated in terms of the biomass proportion within a trawl sample. See Brodziak and Link (2002) for related details, and Ludwig and Reynolds (1988) for a further discussion of diversity.

Key Points and Major Observations

Species evenness has had no apparent trend in the Mid-Atlantic Bight.

J. Food Web Indices

1. Silver hake linkage density

Time: 1973 - 1998

Spatial: Shelf wide

Contributed by: Link

Figure B.37

Methodology and Data Source

These data are derived from the NEFSC Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling.

Key Points and Major Observations

This metric measures number of species eating and being eaten by silver hake. Silver hake is a "canary" population because a large amount of energy passes through this species, i.e., it eats many species and many species eat it. The same is true for red hake (not shown). The number of prey species consumed by silver hake declined in the mid 1980s, but has increased through the mid 1990s. Do these changes reflect an overall change in number of species in ecosystem?

2. Total consumption by 12 piscivores

Time: 1977 - 1997

Spatial: primarily Georges Bank

Contributed by: Overholtz

Figure B.38

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption estimation, see Overholtz et al. (2000).

Key Points and Major Observations

Total consumption (all prey) by 12 predatory fish (pollock, goosefish, cod-2 stocks, spiny dogfish, white hake, weakfish, winter skate, summer flounder, bluefish, red hake, spotted hake, and silver hake) averaged 1.5 million mt and ranged between 1.3 and 2.9 million mt during 1977-1997. Consumption peaked in the early 1980s and declined steadily through 1997. This trend is consistent with the large biomass of elasmobranchs and groundfish that were present during the 1980s and a subsequent large decline in spiny dogfish, cod, white hake, and bluefish, due to fishing, during the later period. Total annual consumption by individual predators was lowest by goosefish and summer flounder and highest by silver hake, and spiny dogfish. Consumption estimates for individual predator species spanned nearly three orders of magnitude and was heavily influenced by predator abundance. As an example, spiny dogfish consumed an average of 619,000 mt, bluefish, 108,000 mt, and goosefish, 14,000 mt during 1977-1997.

3. Total fish consumption by six piscivores on Georges Bank

Time: 1977 - 1998 in three year blocks

Spatial: Georges Bank

Contributed by: Link

Figure B.39

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption estimation, see Link and Garrison (2002a).

Key Points and Major Observations

There was a peak in the early 1980s due to an abundance of extra large cod. Consumption by silver hake and cod dominated 1977 and 1980 values; consumption by dogfish dominated the rest of the time series. The total consumption was relatively consistent aside from the one peak.

4. Consumption of prey species by 12 piscivores

Time: 1977 - 1997

Spatial: Shelf wide

Contributed by: Overholtz

Figure B.40 (a-f)

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption estimation, see Overholtz et al. (2000).

Key Points and Major Observations

Consumption of pelagic fishes and squids by the 12 predators varied greatly during 1977-1997 and was particularly large in some years on herring and sandlance. Predation on sand lance reached high levels in the late 1970s and early 1980s, coincident with the large biomass of this species present at the time and major declines in Atlantic mackerel and herring. As the Atlantic mackerel stock began to recover, predation on mackerel increased, reaching 89,000 mt in 1988.

This was followed by an increase in herring consumption to over 200,000 mt during 1992 and 1993, declining to about 100,000 mt in 1997. Consumption of short-finned and long-finned squid averaged 24,000 and 46,000 mt during 1977-1997, but remained relatively constant over this period. Predation on butterfish was more variable than the other species, but with the exception of a few years , was relatively low. The recent decline in consumption of these species is directly related to declines in the biomass of key predators such as spiny dogfish, cod, white hake, and bluefish. Earlier studies (Bowman and Michaels 1984) suggest that these prey, especially sand lance, herring and mackerel, were important in the diets of these key predatory fish prior to 1977.

5. Snapshot of food web for three years in three different decades

Time: 1977, 1987, and 1997

Spatial: Shelf wide

Contributed by: Link

Figures B.41, B.42, and B.43

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption estimation, see Overholtz et al. (2000) and Link and Garrison (2002a).

Key Points and Major Observations

The size of the circle is proportional to the size of population; the thickness of an arrow shows how much of the population is consumed by predator. During1977, squid and sand lance were the major prey and this was a relatively simple food web. During 1987 and 1997, this was a much more complex food web, with the major groundfish populations lower in abundance and the importance of pelagics as prey more notable.

6. Fish consumption and % fish in diet of cod

Time: 1978 - 1997

Spatial: Shelf wide

Contributed by: Link

Figure B.44

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption estimation, see Overholtz et al. (2000) and Link and Garrison (2002a).

Key Points and Major Observations

There was a peak in the early 1980s for both how much fish comprised the diet of cod and how much fish biomass was consumed by cod. Lower values in the 1990s likely reflect the smaller size structure of the cod population.

7. Fish consumption by cod at age

Time: 1978 - 1997

Spatial: Shelf wide

Contributed by: Link

Figure B.45

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption estimation, see Overholtz et al. (2000) and Link and Garrison (2002a).

Key Points and Major Observations

There is an overall decline in the amount of total fish consumed by cod seen here and in Figure B.44. The amount of fish eaten by cod at different ages varied over time. Through the 1980s and into the 1990s, the relative and absolute amount of fish eaten by age 7+ cod declined. In early to mid 1990s older fish (ages 7+) were a smaller component of the population and contributed a relatively smaller proportion of the amount of fish consumed relative to age 3-5 cod.

8. Cod % diet composition of major fish prey

Time: 1973 - 1997

Spatial: Shelf wide

Contributed by: Link

Figure B.46

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For further details see Link and Garrison (2002b).

Key Points and Major Observations

This demonstrates the transfer of energy from pelagic to benthic environment. It also seems to show prey switching based upon prey availability.

9. Spiny dogfish % diet composition of major fish prey

Time: 1973 - 1997

Spatial: Shelf wide

Contributed by: Link

Figure B.47

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling.

Key Points and Major Observations

The dogfish diet seems to track prey availability. The diet of dogfish is comprised mainly by pelagic prey.

10. Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake

Time: 1973 - 1998

Spatial: Shelf wide

Contributed by: Link

Figure 48 (a-f)

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling.

Key Points and Major Observations

This metric is a measure of food web linkage density. There are some notable changes over time, particularly an increase in red hake and herring predators in more recent years.

11. Silver hake % cannibalism

Time: 1973 - 1998

Spatial: Shelf wide

Contributed by: Link

Figure B.49

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. These data represent what fraction of silver hake diet consists of silver hake.

See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling.

Key Points and Major Observations

When other prey are not available, silver hake are cannabilistic. This phenomena has a consistently high occurrence, with in an increasing trend in the mid 1990s. How this impacts population dynamics is unclear.

12. Silver hake and red hake number of prey items

Time: 1973 - 1998 (with 4 year moving averages overlaid)

Spatial: Shelf wide

Contributed by: Link

Figure B.50

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling.

Key Points and Major Observations

There was a decrease in the number of prey consumed by silver hake in mid 1980s, with an increasing number of prey throughout the 1990s. The number of prey of red hake has increased continuously until the mid 1990s. The two hakes show similar patterns and also exhibit similar diets.

13. Herring consumption to landings ratio

Time: 1977 - 1997

Spatial: Shelf wide

Contributed by: Overholtz

Figure B.51

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption and landings information, see Overholtz et al. (2000).

Key Points and Major Observations

Consumption of Atlantic herring was below 50,000 mt from 1977-1987 and then increased in the 1990s to over 200,000 mt in some years. Landings for this species averaged 82,000 mt during 1977-1997. As herring increased in the 1990s, consumption to landings ratios increased dramatically in the early 1990s and then declined. If predator fish biomass is allowed to recover we would expect consumption of this species to increase and greatly exceed landings in the future.

14. Mackerel consumption to landings ratio

Time: 1977 - 1997

Spatial: Shelf wide

Contributed by: Overholtz

Figure B.52

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption and landings information, see Overholtz et al. (2000).

Key Points and Major Observations

Consumption and landings of Atlantic mackerel by 12 predatory fish were fairly similar during 1977-1997 and both were well below established reference points for this species (MSY 326,000 mt). Consumption to landings ratios for this species were relatively constant during 1977-1997. This suggests that a recovery in predator biomass may not cause any large increases in consumption on this species, with the exception perhaps of a large recruiting year-class. Several factors such as fast swimming speed and enhanced growth rates, allowing for a larger body size, probably make Atlantic mackerel less available or suitable to this suite of 12 predators.

15.* Loligo *consumption to landings ratio

Time: 1977 - 1997

Spatial: Shelf wide

Contributed by: Overholtz

Figure B.53

Methodology and Data Source

These data are derived from both the NEFSC Bottom Trawl Survey Data and the Food

Habits Database. See Link and Almeida (2000) for further details on the food habits sampling and Azarovitz (1981) for the bottom trawl survey sampling. For specifics on the consumption and landings information, see Overholtz et al. (2000).

Key Points and Major Observations

Consumption of long-finned squid exceeded landings and MSY (24,000 mt) in all years except 1993 and 1994. Consumption to landings ratios for this species were relatively high throughout the 1977-1997 period, averaging 2.36 and ranging from 0.58-4.88. This suggests that any increase in predator biomass will translate into an immediate increase in consumption of this species by predatory fish. Consumption will probably always be in excess of sustainable landings for this species.

K. System Level Indices

We recognize that there are also several system level indices that one could estimate to ascertain the status of this ecosystem. For example, what are the values for emergy, exergy, free energy, information content, energy flows, system level consumption, metabolism, and production, total production, total biomass, and flux rates across time? Similarly, how strong is the resilience, persistence, resistance, or stability of the system? Not much is known in general or in a time series sense for these measure, but these emergent metrics could be estimated in future efforts.

L. Summary of Biotic Metrics

We examined biotic metrics ranging from single species to ecosystem level.

The early to mid 1980s seem to have a consistent "blip" in many of the graphs. The cause of these peaks or troughs are currently unknown. Some potential hypotheses include a change in the "environmental condition" (not specified), removal of the foreign fishing fleets in 1976 and changes in management during the late 1970s and early 1980s, predatory release due to changes in overall selectivity, changes in the trophic linkages, alteration of habitat, or some combination thereof.

Total biomass (as measured by the trawl survey time series) has been remarkably consistent from the late 1960s to present given the large changes observed in biomass of individual species.

Changes in the abundance and diversity of commercially important species and associated bycatch species should be interpreted in light of changing management measures over time. In particular, the implementation of the closed areas since 1995 may influence these trends.

Are systematic (taxonomic) or trophic (functional) groupings more important for providing information? Would plotting fishing pressure on graphs of fish biomass improve our understanding? Similarly, would a similar plot against environmental variables improve our understanding? These and a suite of related questions merit examination in the future.

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Table 4.1. Abundance estimates of marine mammals and protected species in U.S. waters of the northwest Atlantic.

	Year						
Species	1982	1991	1992	1995	1997	1998	1999
Common dolphin	4201			6743		30768	
Riss's dolphin	11834			5050		29110	
Atl. Spotted dolphin	2441			4772		36439	
Pantropical spotted dolphin				4772		13117	
Bottlenose dolphin	12069			13440		30633	
Striped dolphin	16320			30935		61546	
White-sided dolphin	38016		20400	27157			51640
Harbor porpoise	18934	37500	67500	74000			89700
Pilot whale	8839			8111		14524	
Beaked whales	939			1516		3196	
Humpback whale							816
Sperm whale	1301			2695		4702	
Fin/Sei whale	6075			2229			2814
Minke whale	4945		2650	3810			2998
Loggerhead turtles	7702			4644		6010	
Leatherback turtles	361			3136		1175	
Kemps Ridley turtle				0		2260	
Harbor seal					30990		

Figure B.1. ***Georges Bank, Mid-Atlantic Bight Scallop Biomass, Landings, and Survey Indices***

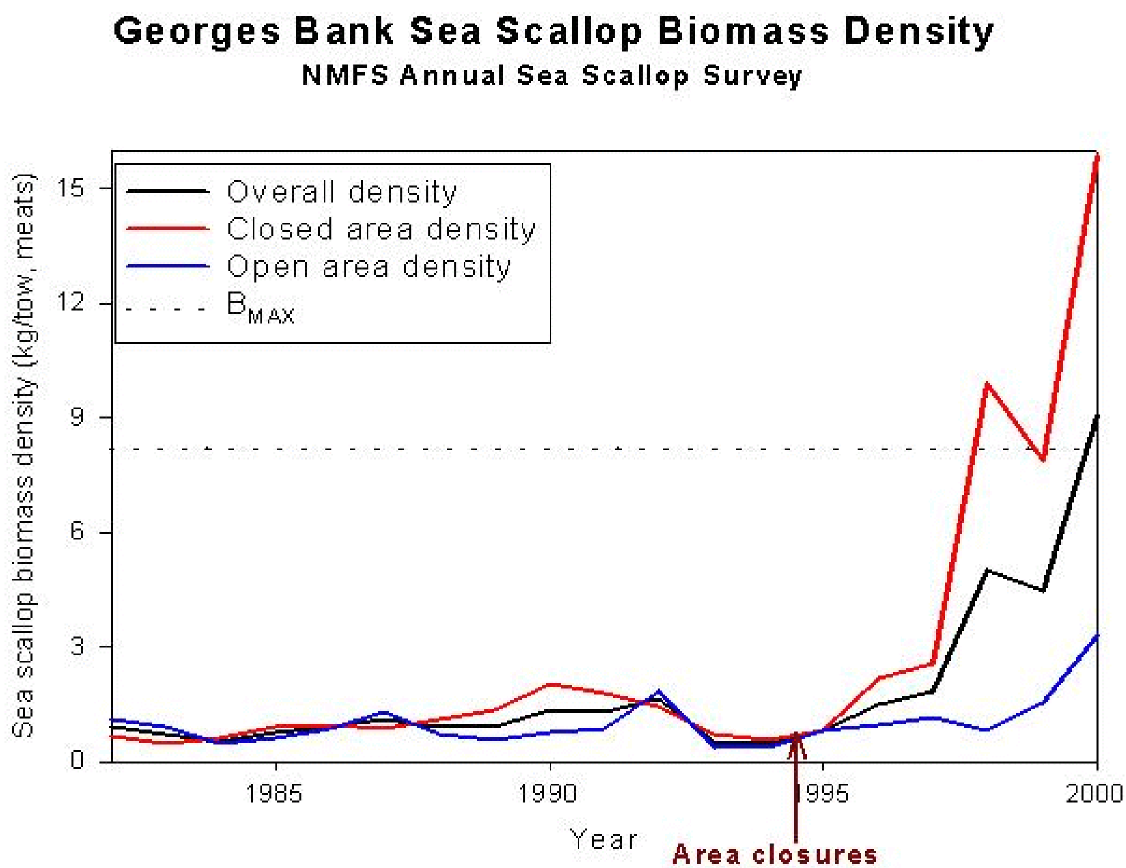


Figure B.2. ***Georges Bank, Mid-Atlantic Bight Scallop Biomass, Landings, and Survey Indices***

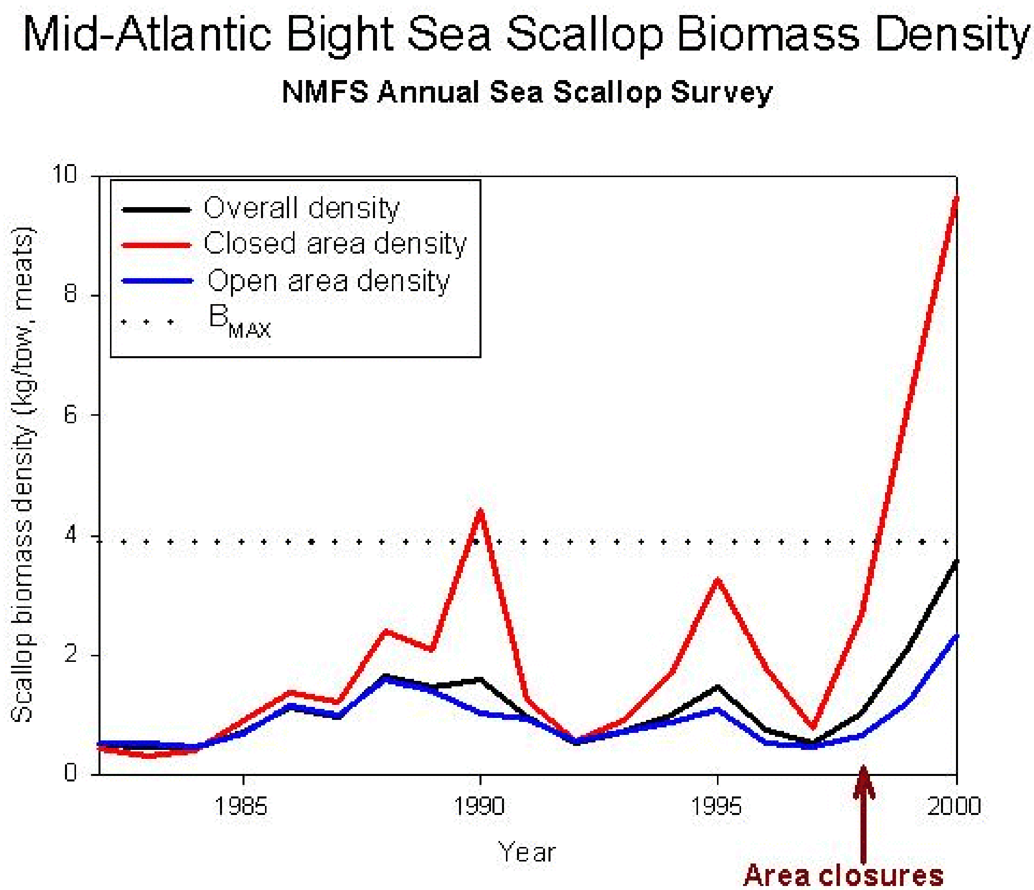


Figure B.3. ***Georges Bank, Mid-Atlantic Bight Scallop Biomass, Landings, and Survey Indices***

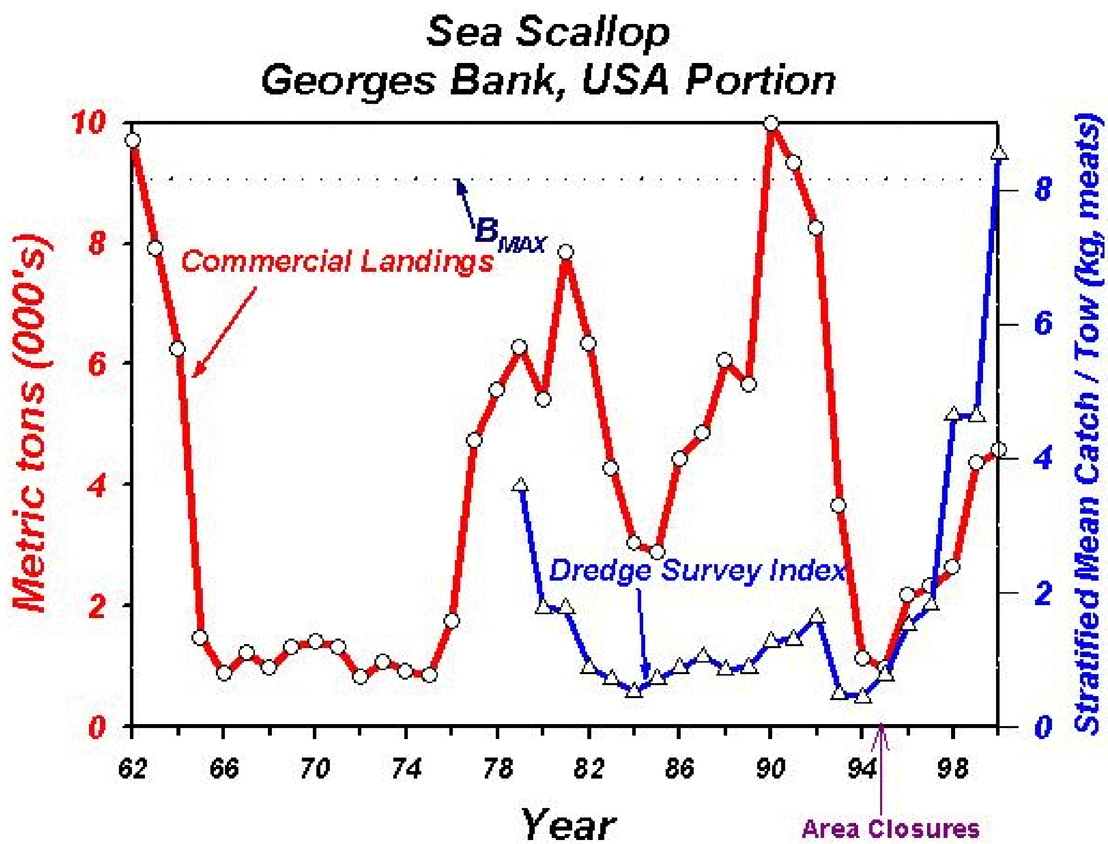


Figure B.4. ***Georges Bank, Mid-Atlantic Bight Scallop Biomass, Landings, and Survey Indices***

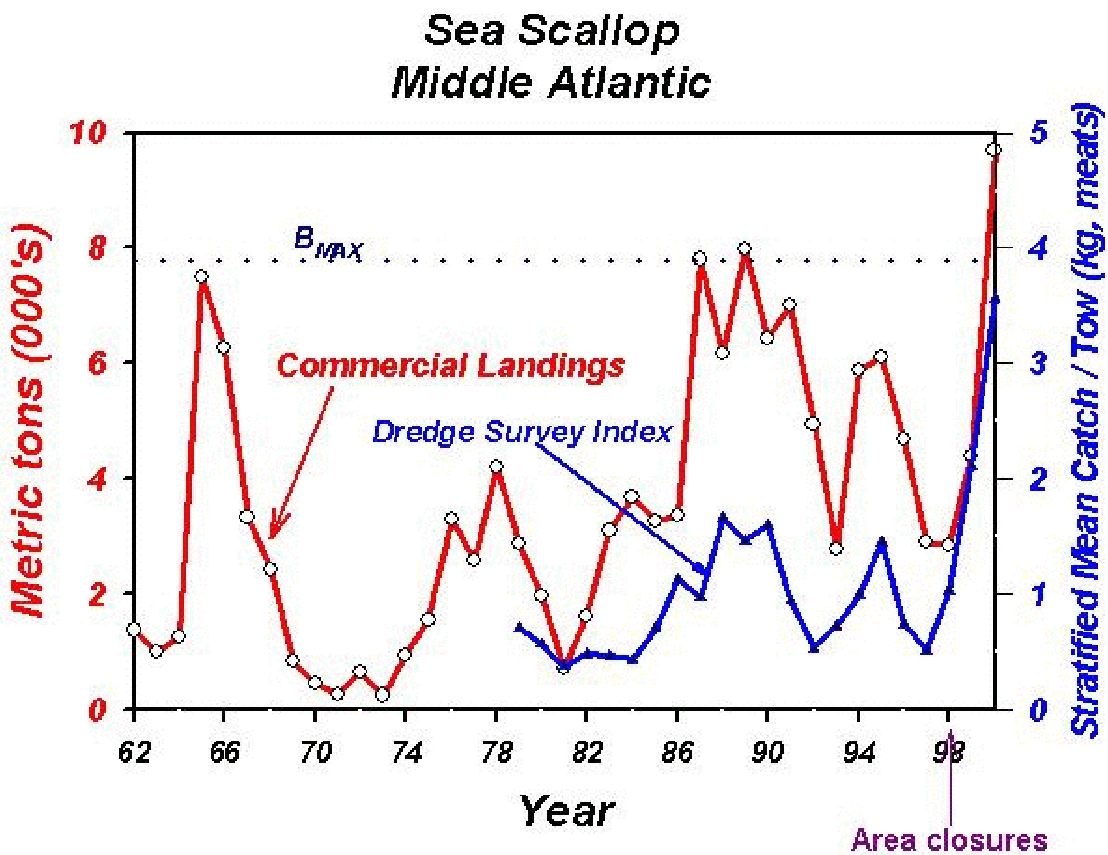


Figure B.5. ***Sculpin abundance from fall bottom trawl survey***

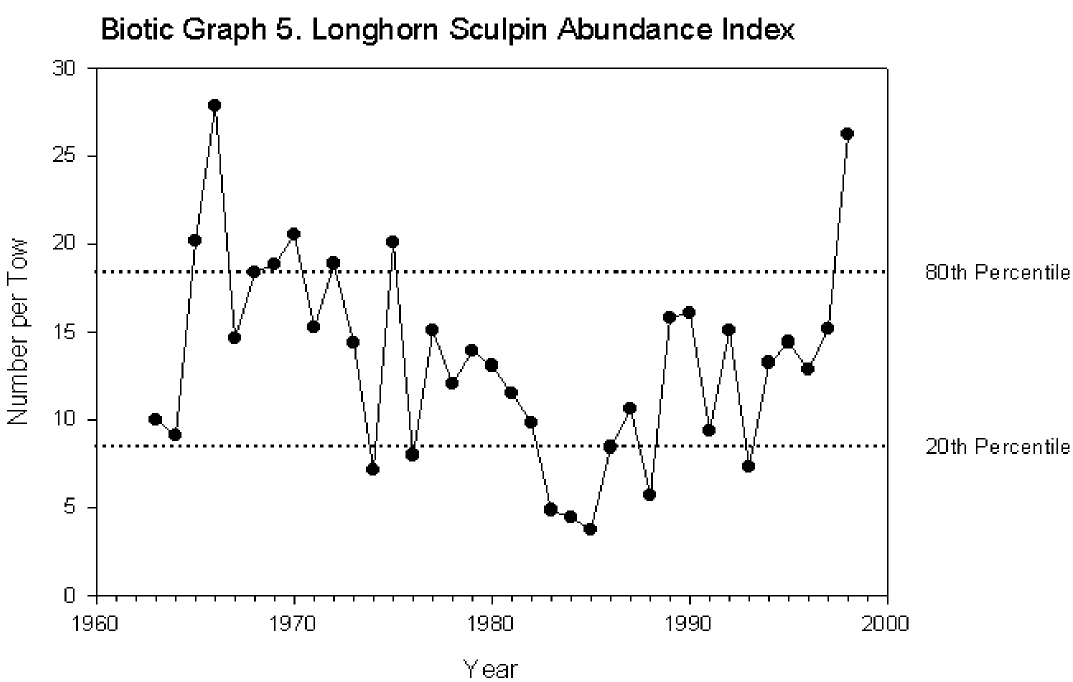


Figure B.6. ***Blue crab abundance***

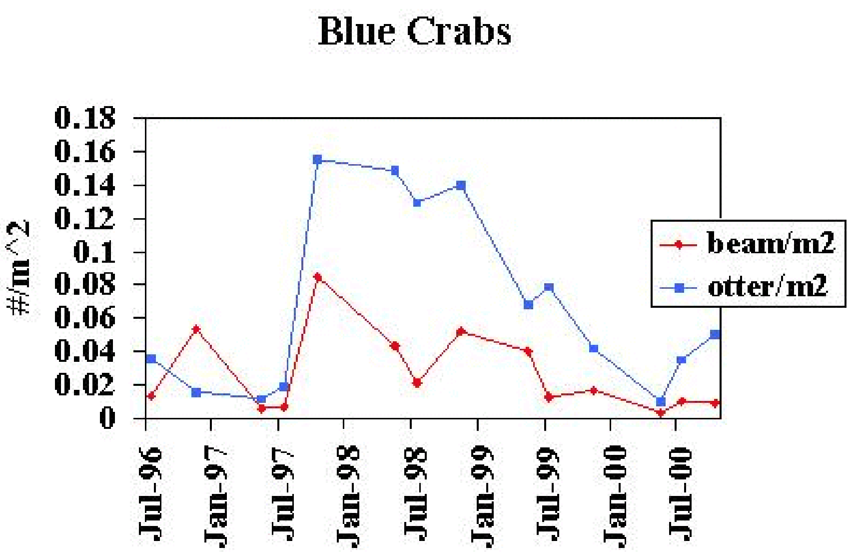
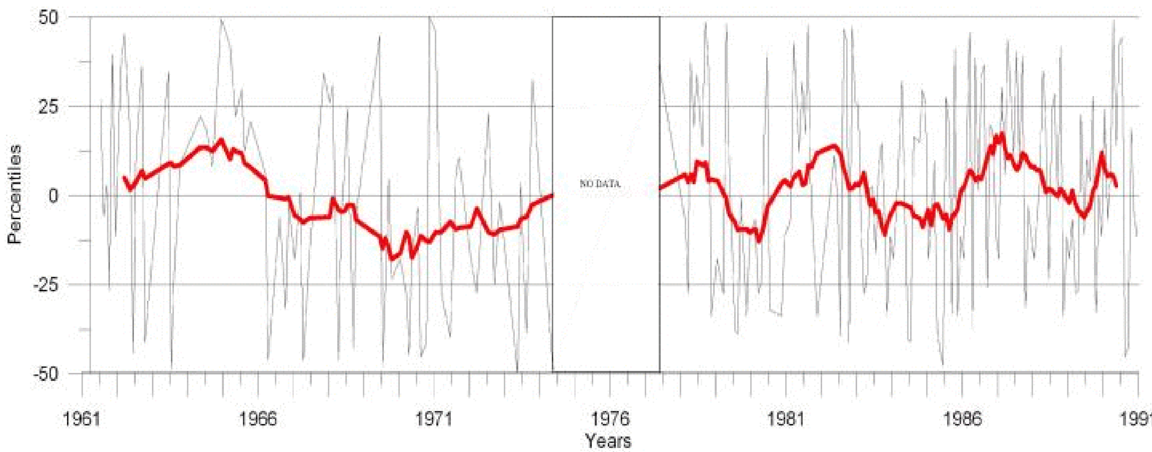


Figure B.7a. ***Central Gulf of Maine* Calanus finmarchicus*, c.1-4, c.5-6 anomalies***



Percentile departures of Calanus spp., c.1-4 from 1961 through 1990 medians in the central Gulf of Maine. Fifteen month running average curve superimposed. From:MARMAP Ships of Opportunity Program.

Figure B.7b. ***Central Gulf of Maine* Calanus finmarchicus*, c.1-4, c.5-6 anomalies***

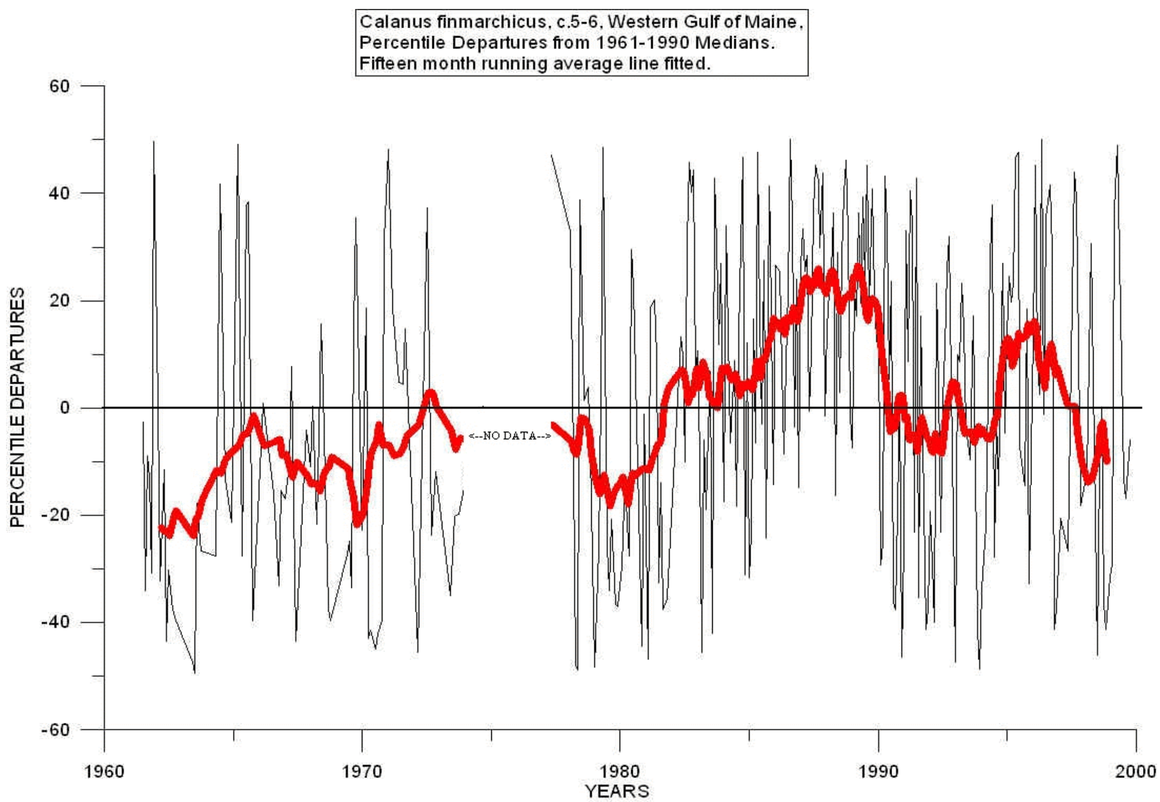
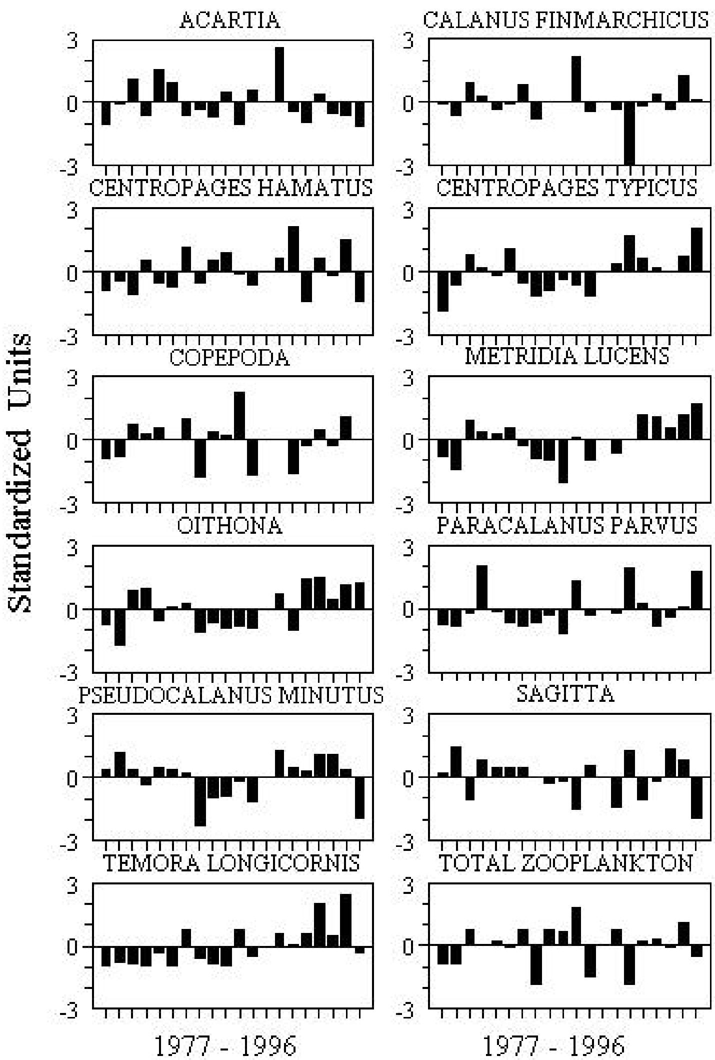
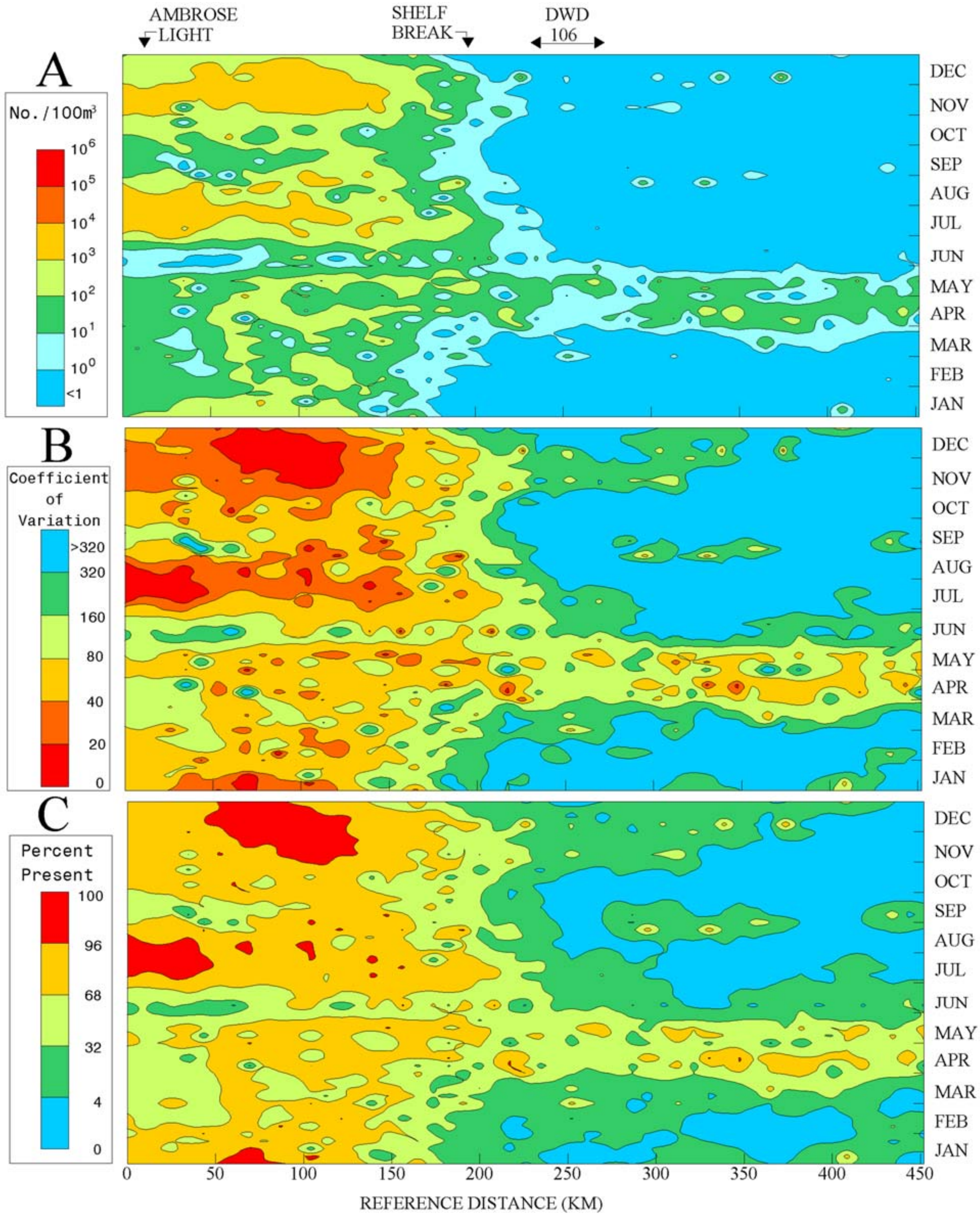


Figure B.8. ***Anomalies of major zooplankton during spring***



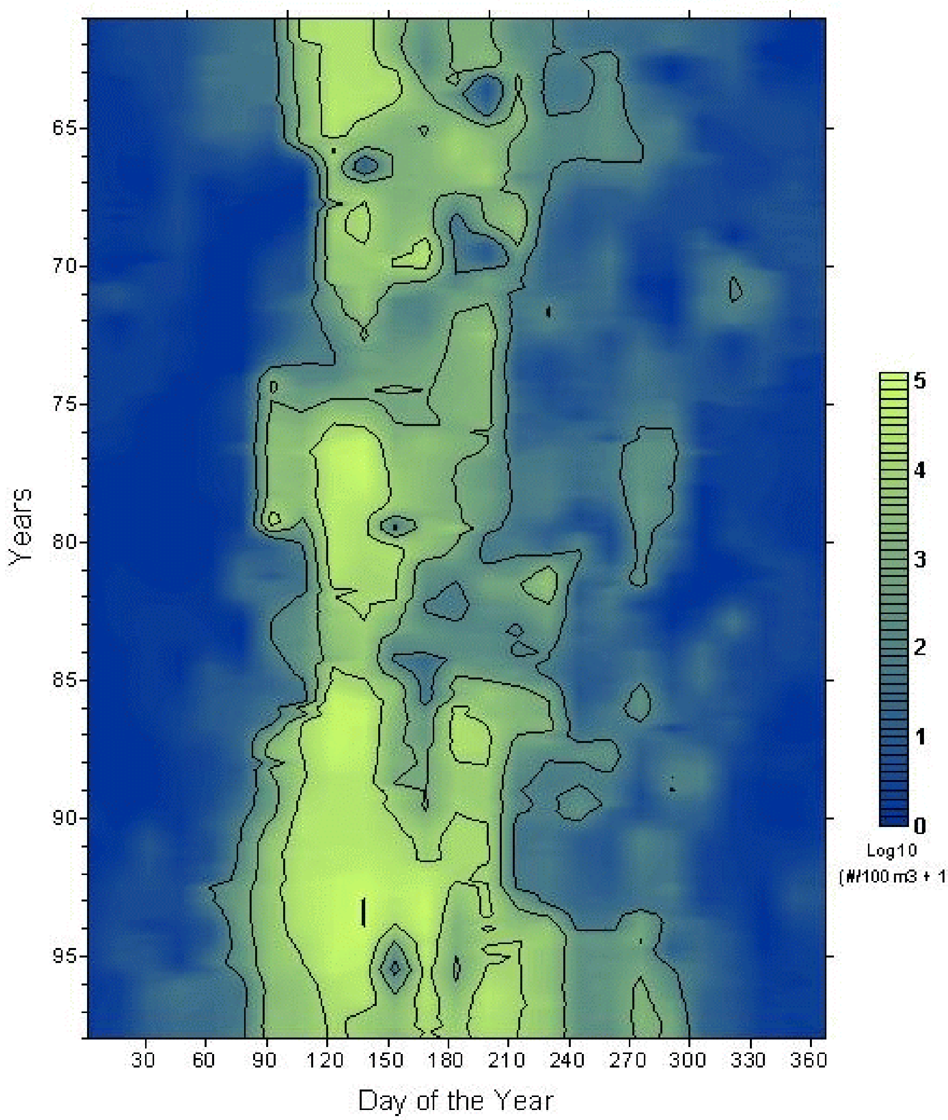
Standardized departures of mean annual plankton abundances during 'spring' (15 Feb - 15 May) on Georges Bank. From: NOAA, NEFSC, MARMAP Surveys.

Figure B.9. Time and space conditions of Centropagus typicus across the continental shelf



Time and space conditions of Centropages typicus, c. 4-6, across the continental shelf and slope southeast of New York City during the 1976 through 1990 base period. A. Base period mean abundance. B. Coefficient of variation about the base period mean. C. Percent of samples during the base period with taxon present. From: Jossi et al., In Review.

Figure B.10. **Calanus** ***abundance by day of year over time***



Calanus finmarchicus, c1-4, between Massachusetts & Cape Sable (10m).
From: MARMAP Ships of Opportunity Program.

Figure B.11. ***The overall zooplankton biomass and abundance trends of two dominant copepods:*** **Calanus finmarchicus** ***and*** **Centropages typicus**

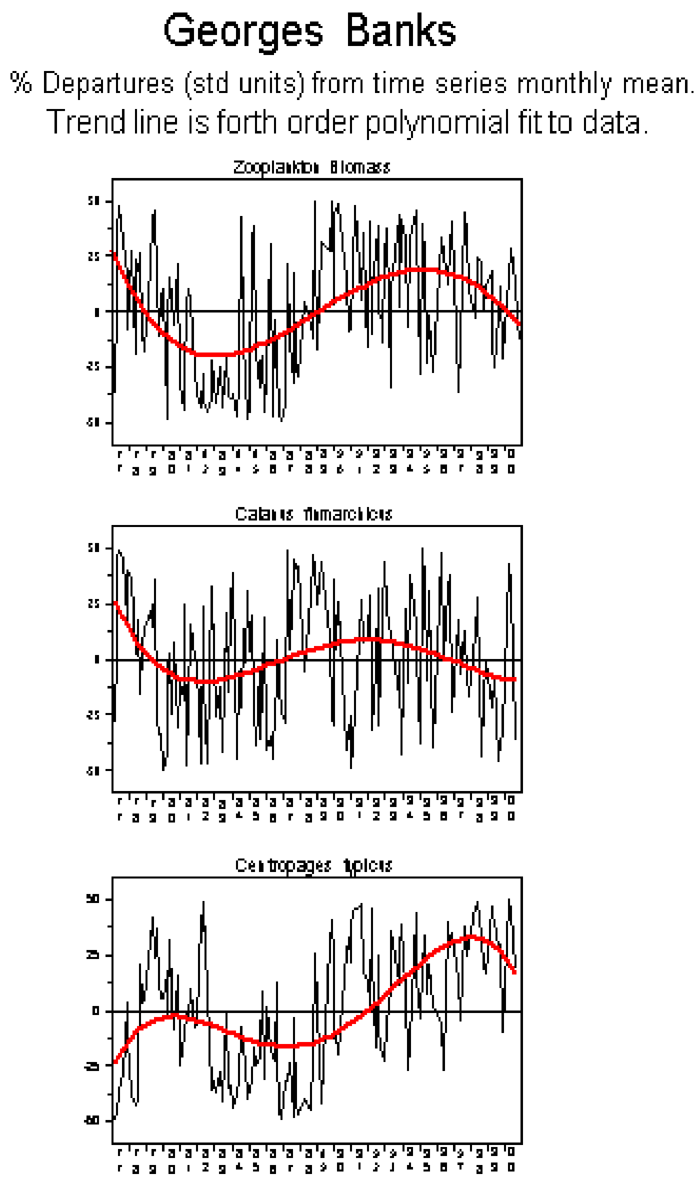


Figure B.12. ***The overall zooplankton biomass and abundance trends of two dominant copepods:*** **Calanus finmarchicus *and* Centropages typicus**

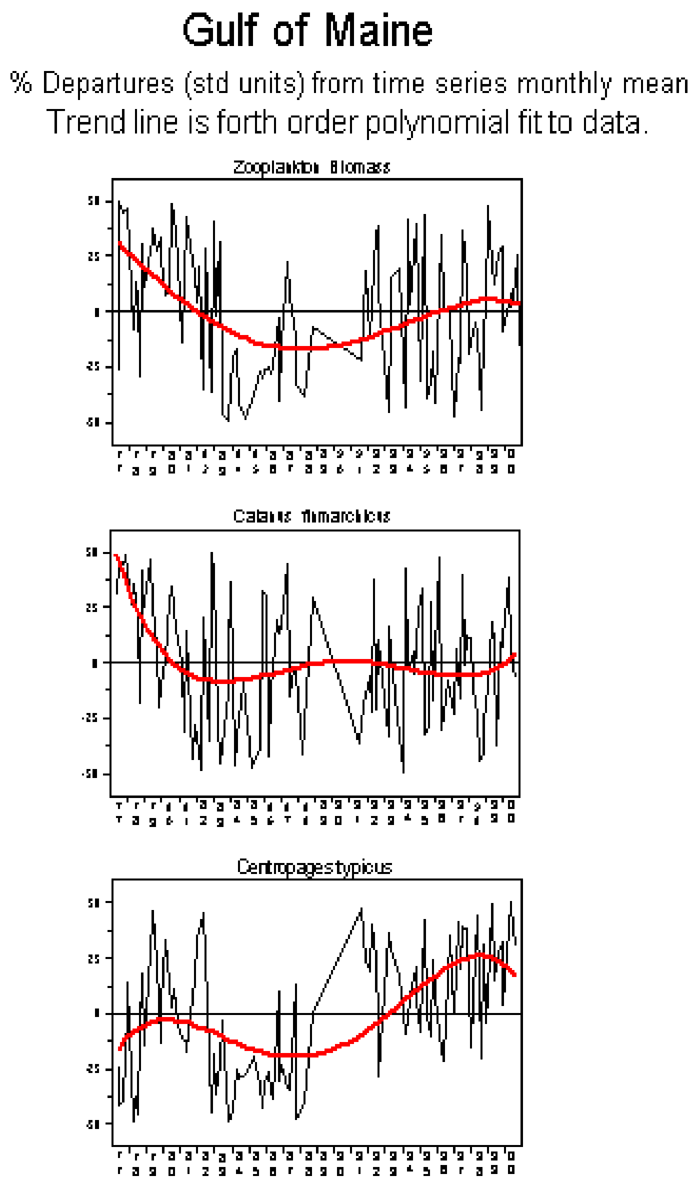


Figure B.13. ***Total Zooplankton Biomass***

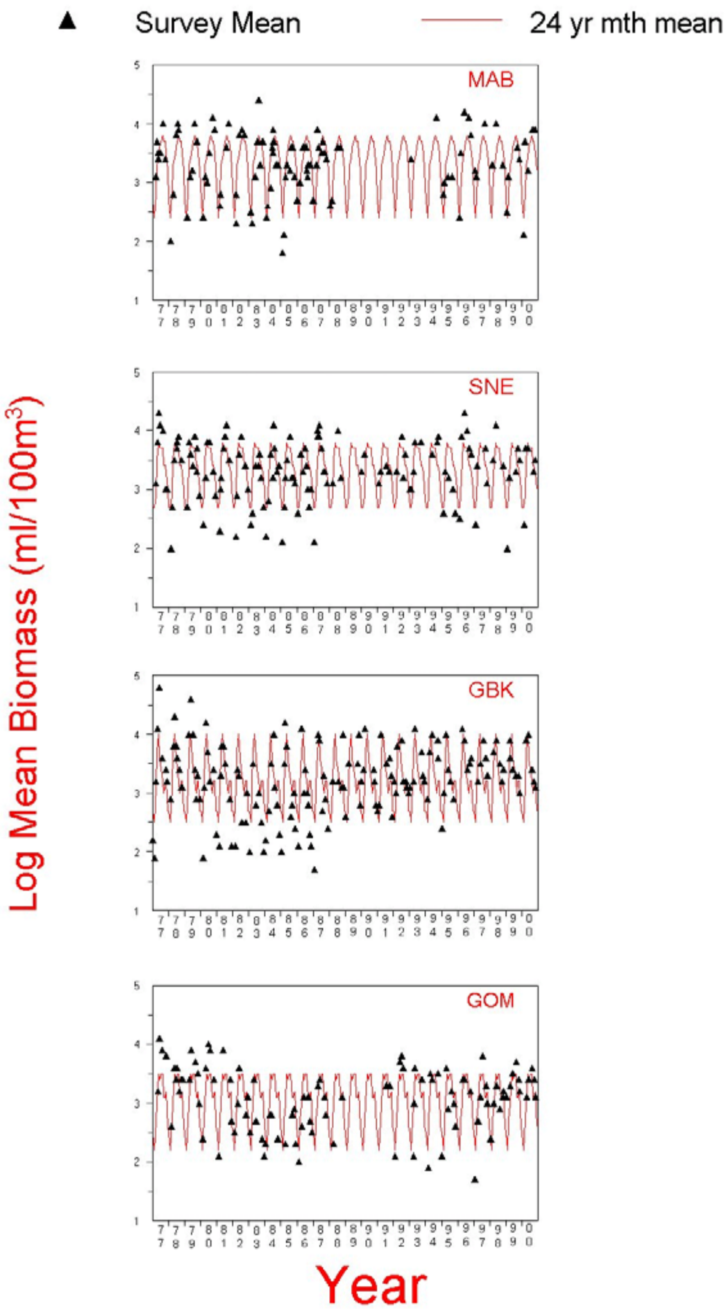


Figure B.14a. ***Relative abundance of northeast species groups (groundfish, pelagics, elasmobranchs, others) from combined fall and spring bottom trawl surveys***

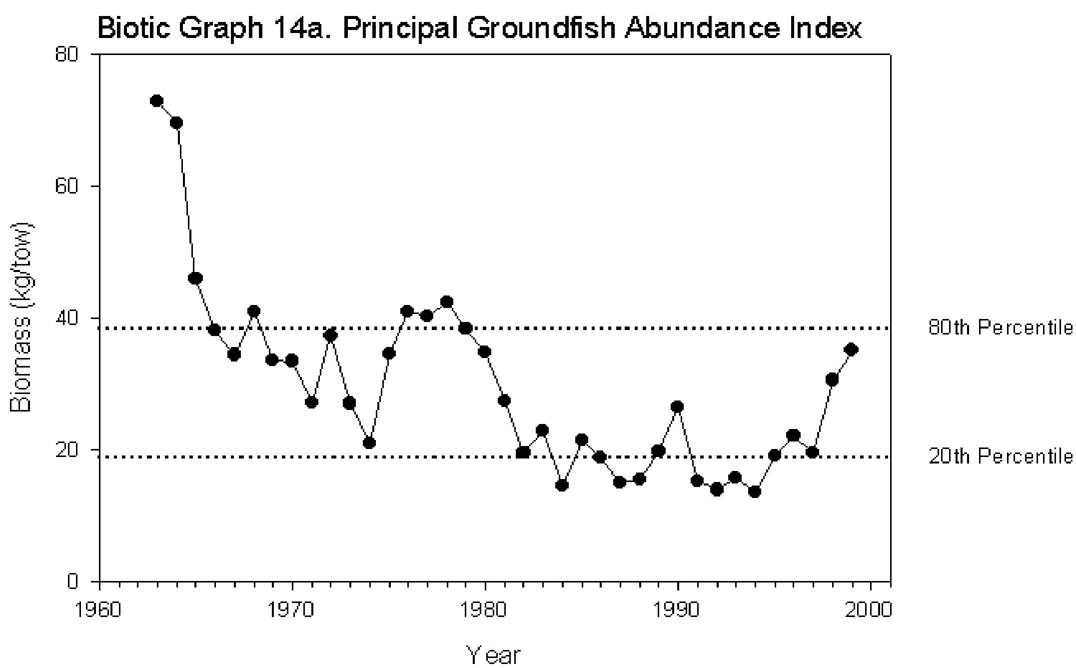


Figure B.14b. ***Relative abundance of northeast species groups (groundfish, pelagics, elasmobranchs, others) from combined fall and spring bottom trawl surveys***

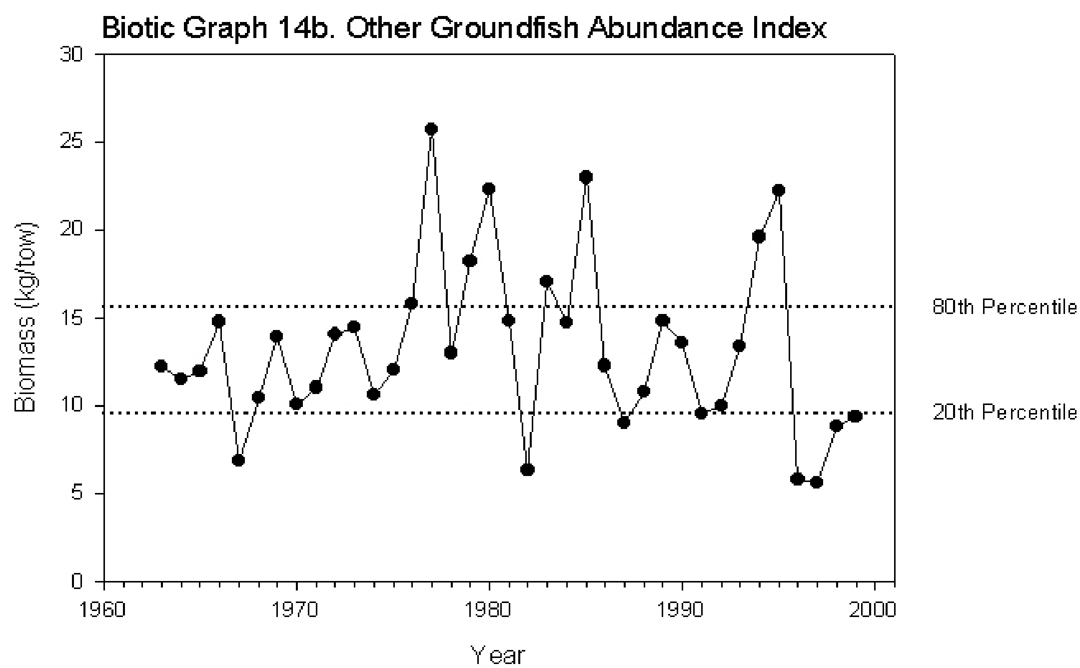


Figure B14c. ***Relative abundance of northeast species groups (groundfish, pelagics, elasmobranchs, others) from combined fall and spring bottom trawl surveys***

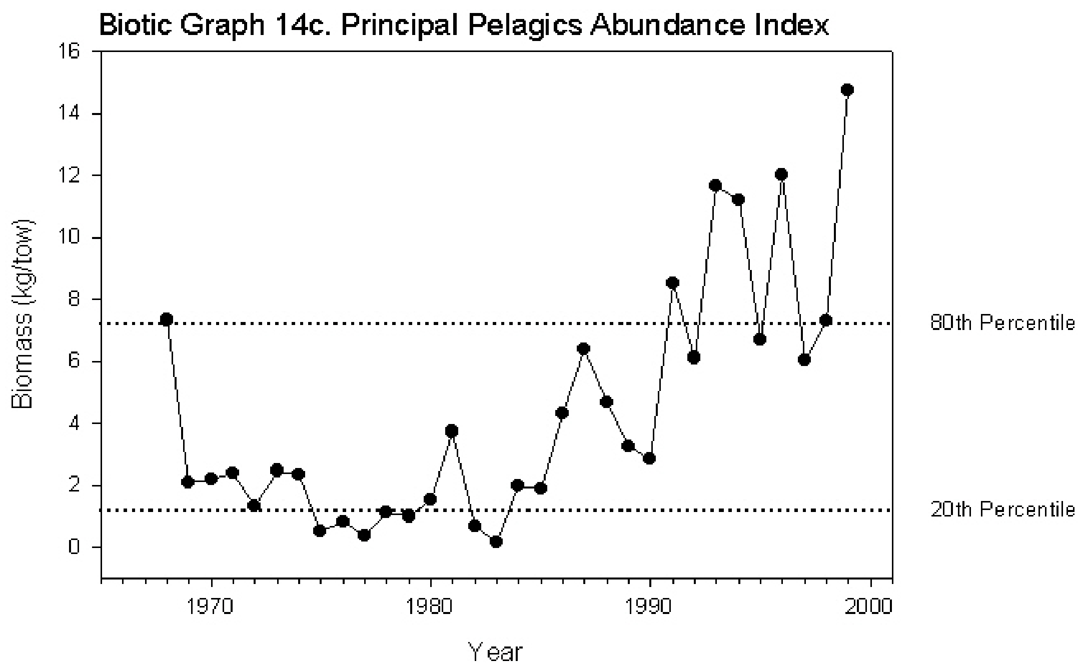


Figure B.14d. ***Relative abundance of northeast species groups (groundfish, pelagics, elasmobranchs, others) from combined fall and spring bottom trawl surveys***

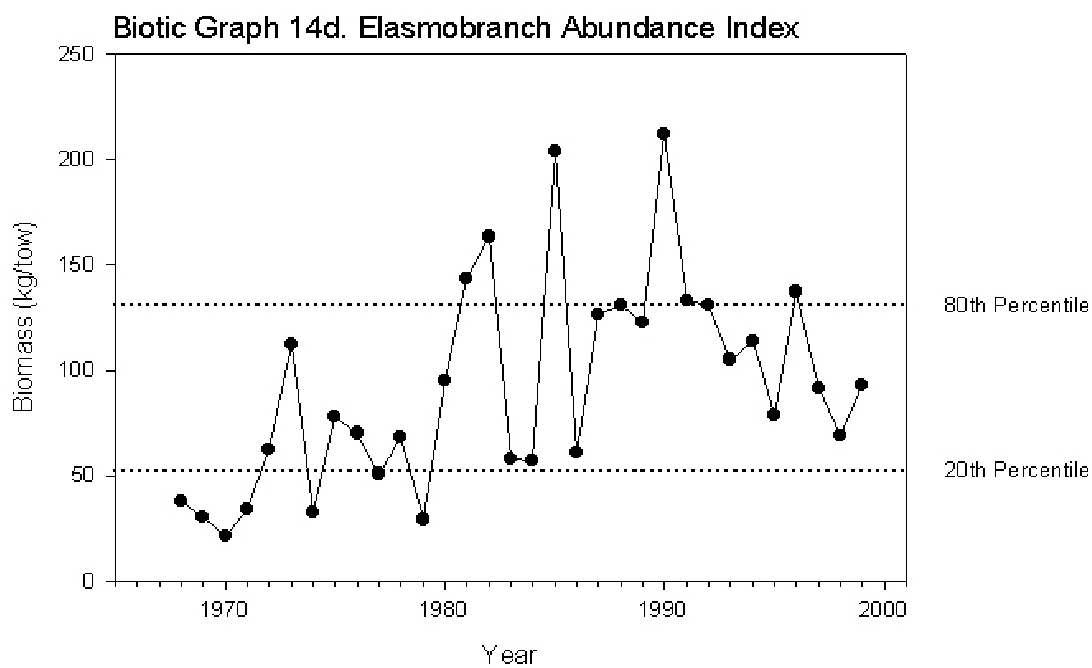


Figure B.15. ***Principal groundfish biomass for Georges Bank from autumn bottom trawl survey***

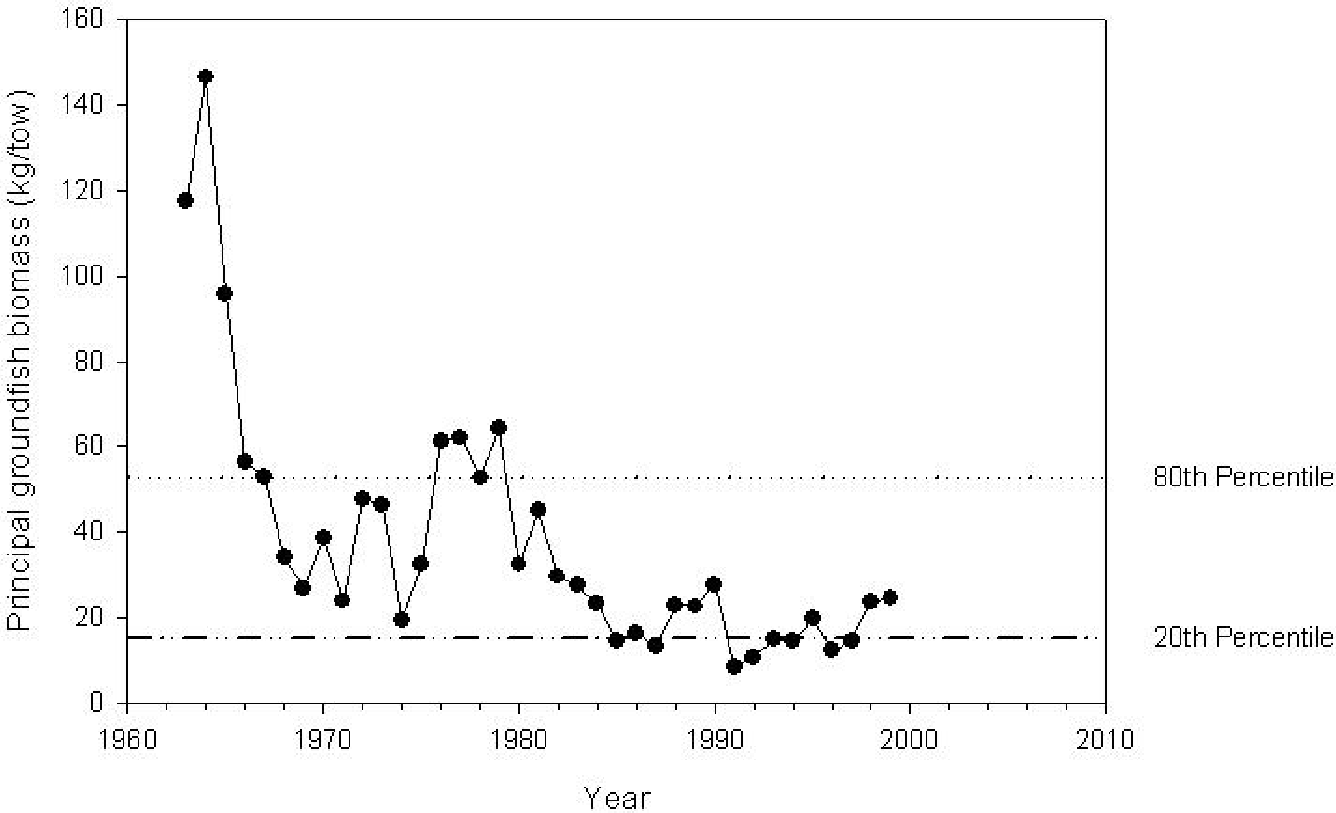


Figure B.16. ***Elasmobranch biomass for Georges Bank from autumn bottom trawl survey***

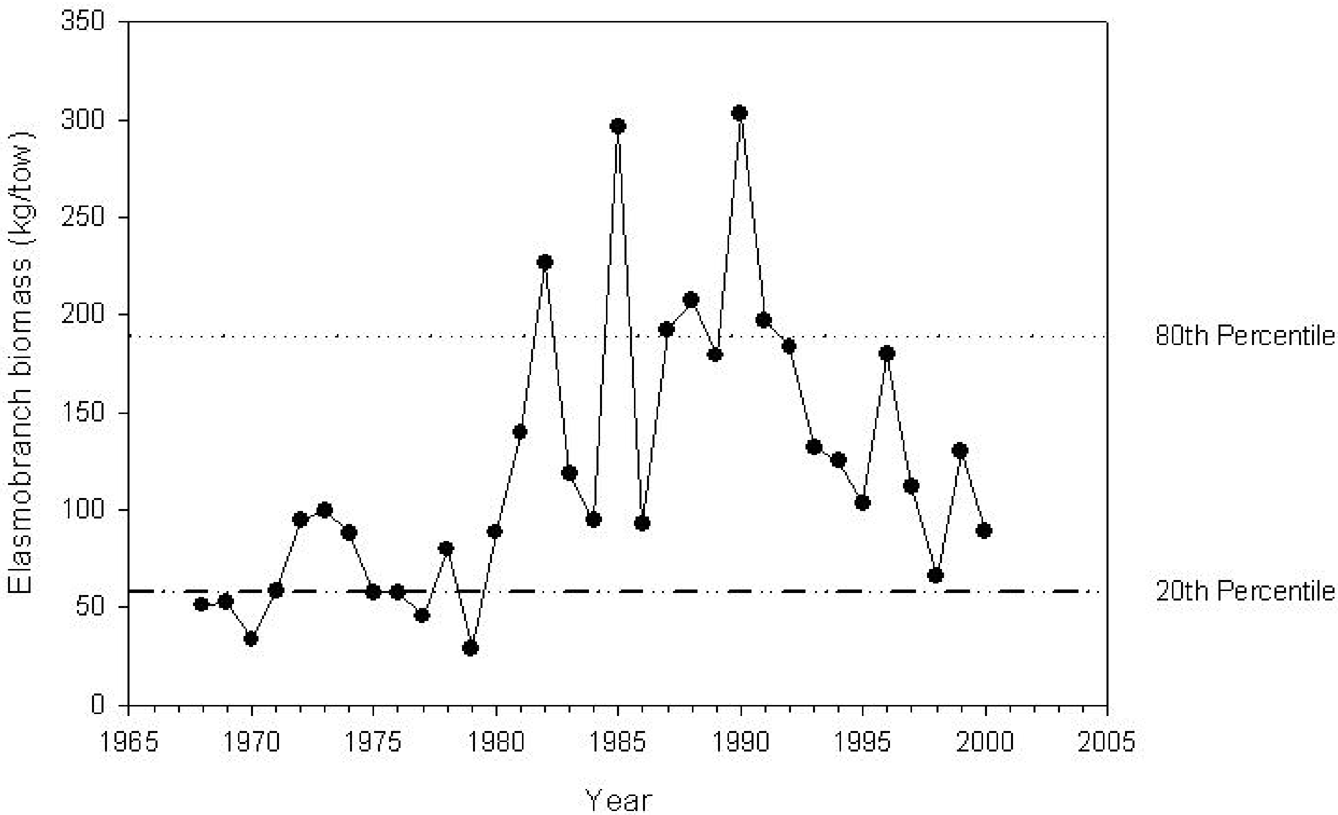


Figure B.17. ***Principal pelagics biomass estimates from recent assessments***

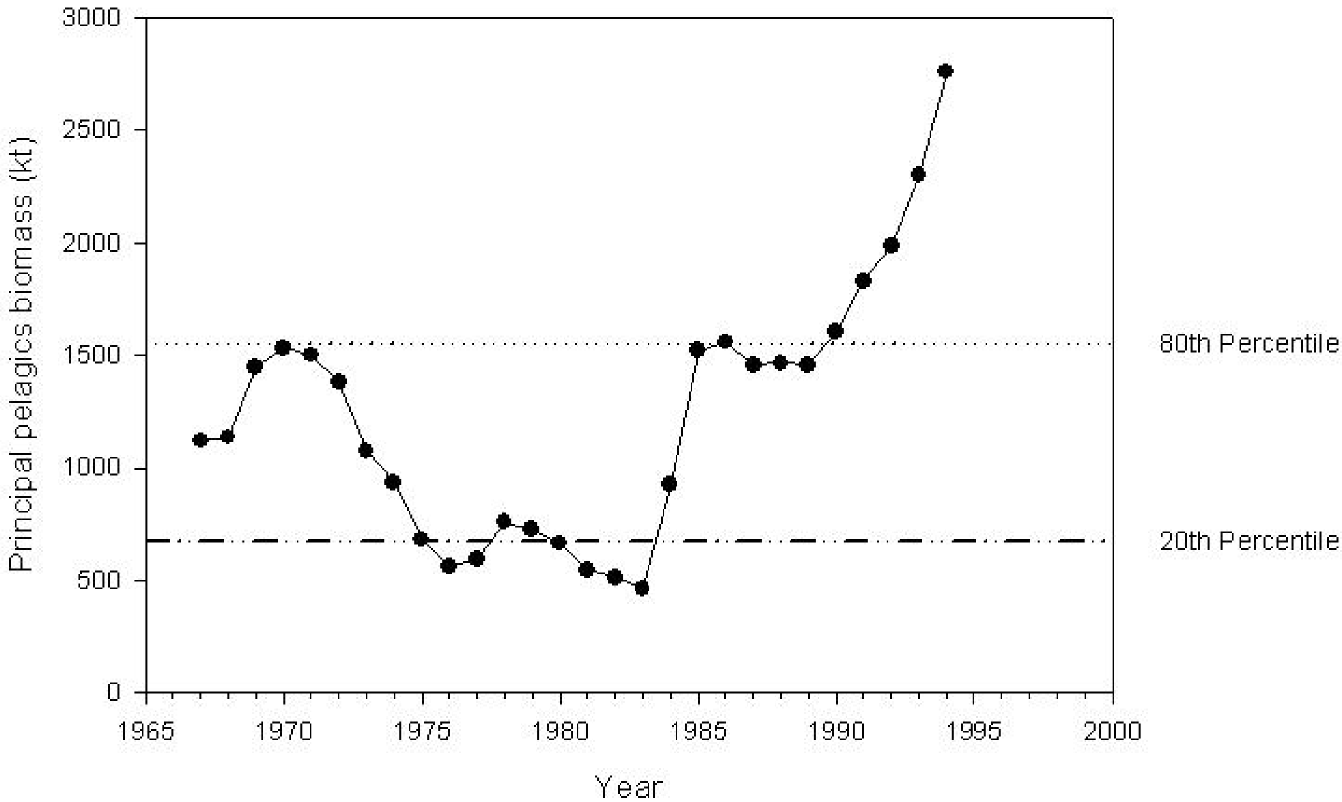


Figure B.18. ***Cephalapod biomass for Georges Bank from fall bottom trawl survey***

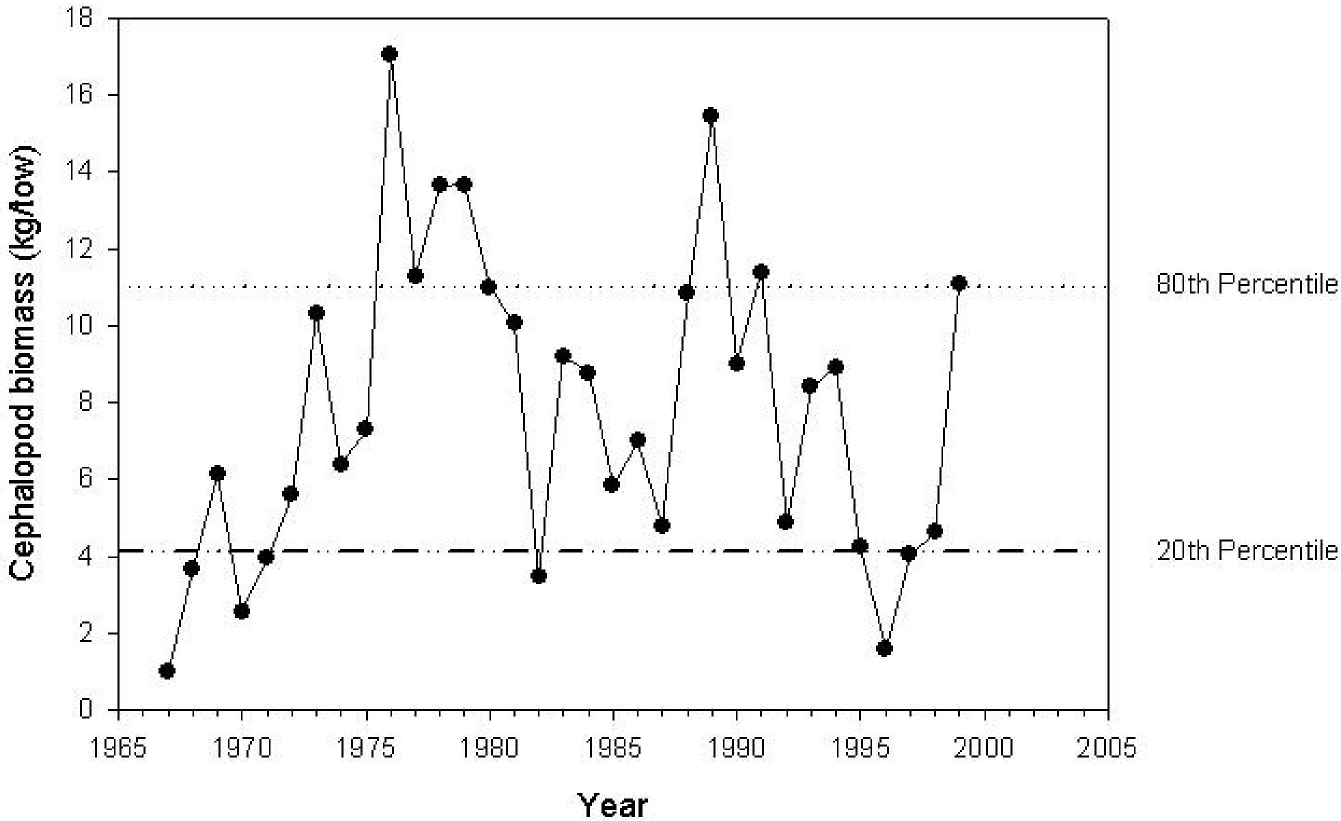


Figure B.19. ***Frequency of occurrence of parasitic nematodes in all predators***

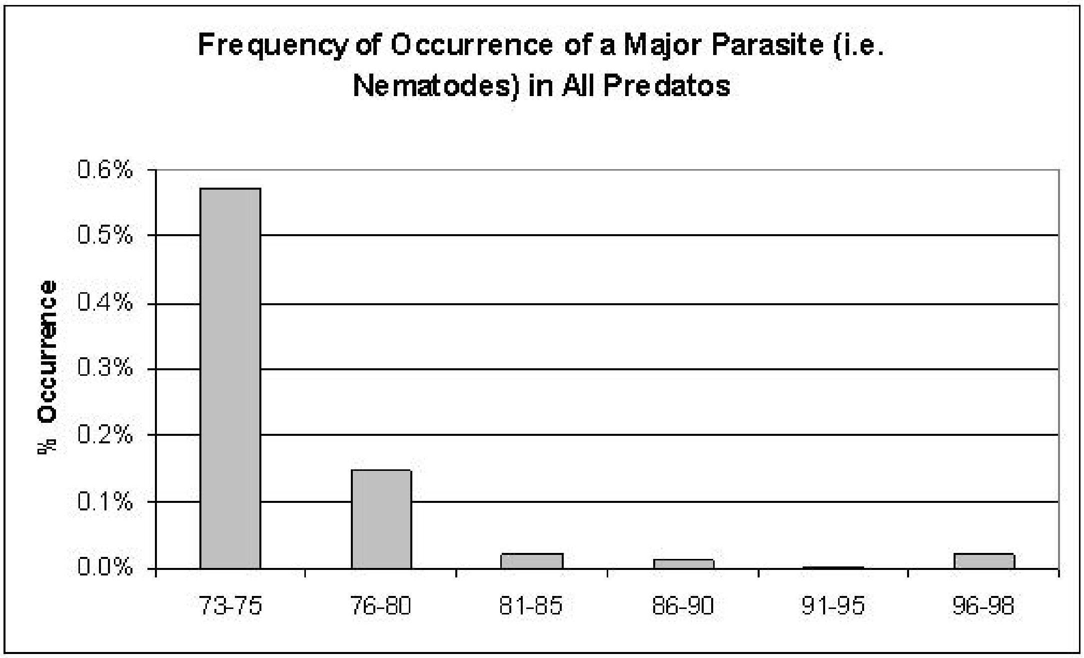


Figure B.20. ***Winter flounder collected by beam and otter trawls***

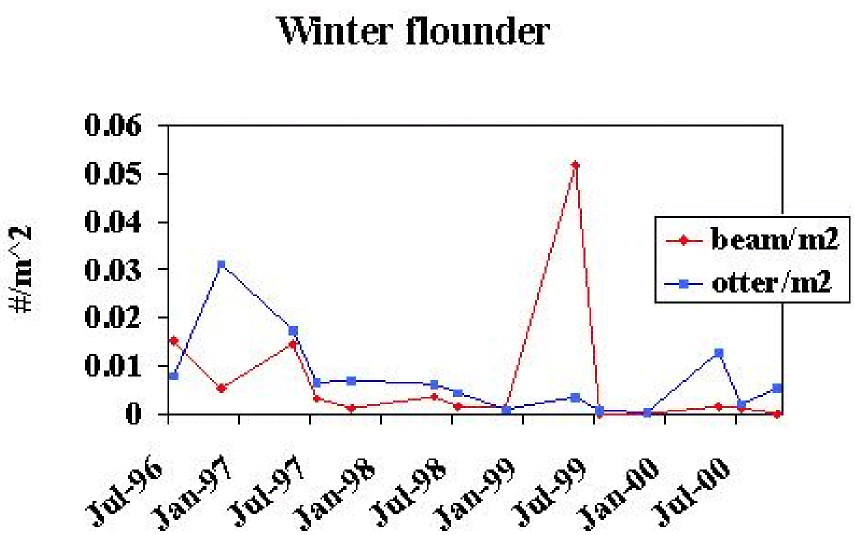
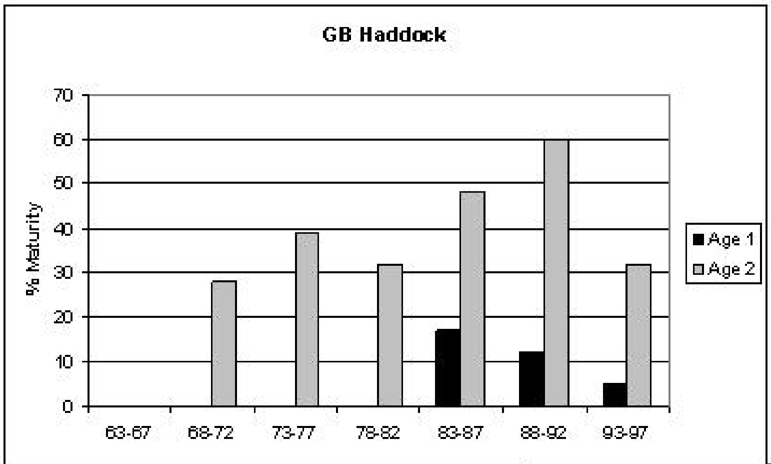


Figure B.21. ***Haddock and cod % maturity for ages 1 and 2***



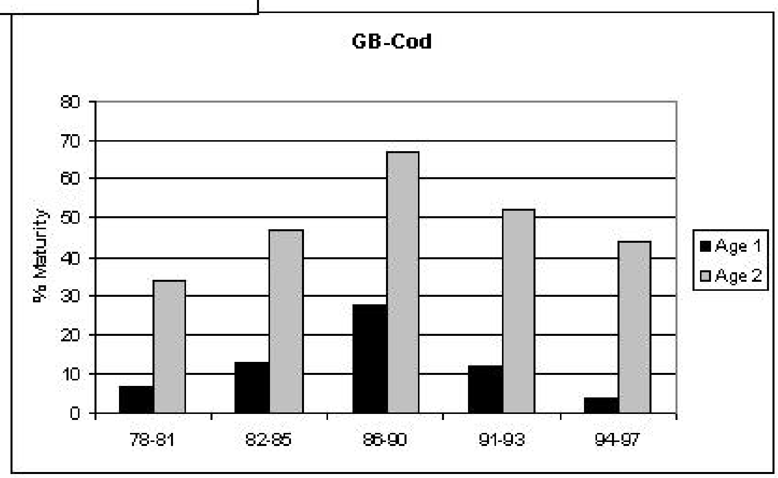


Figure B.22. ***Cod survival ratio anomaly***

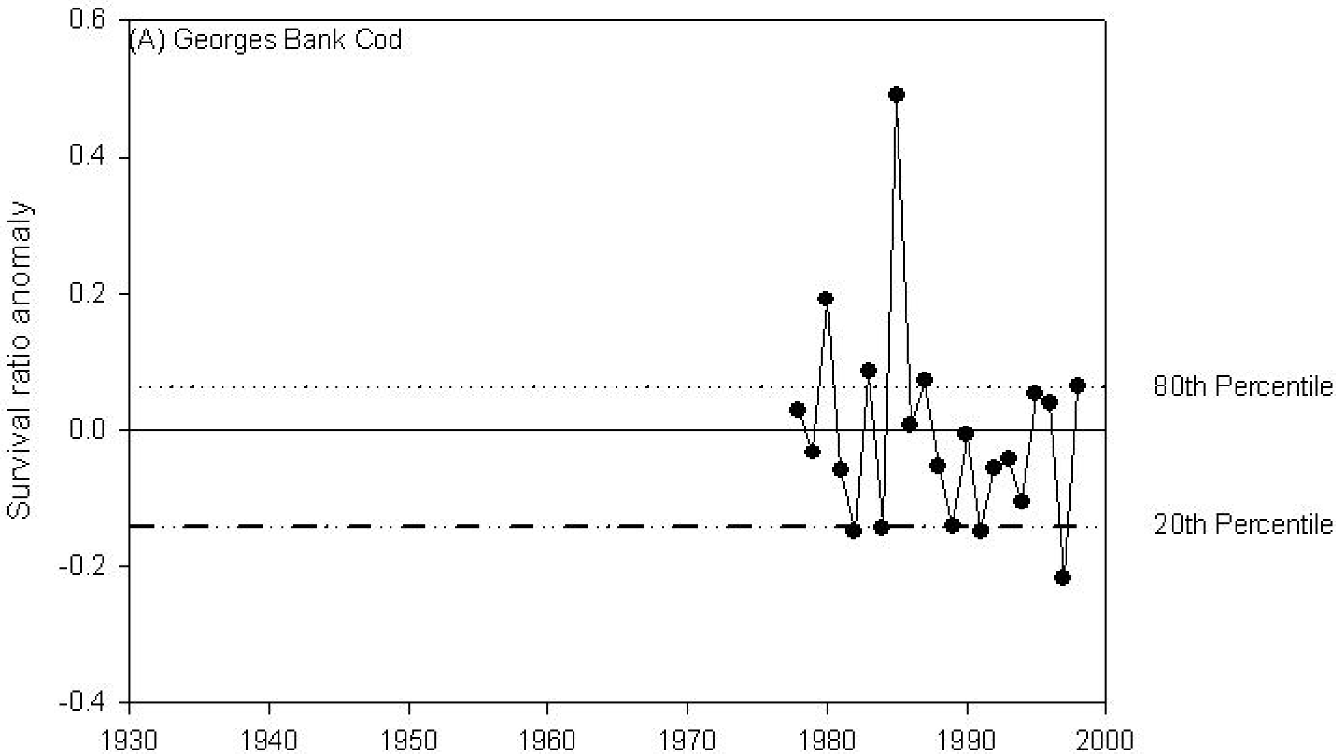


Figure B.23. ***Haddock survival ratio anomaly***

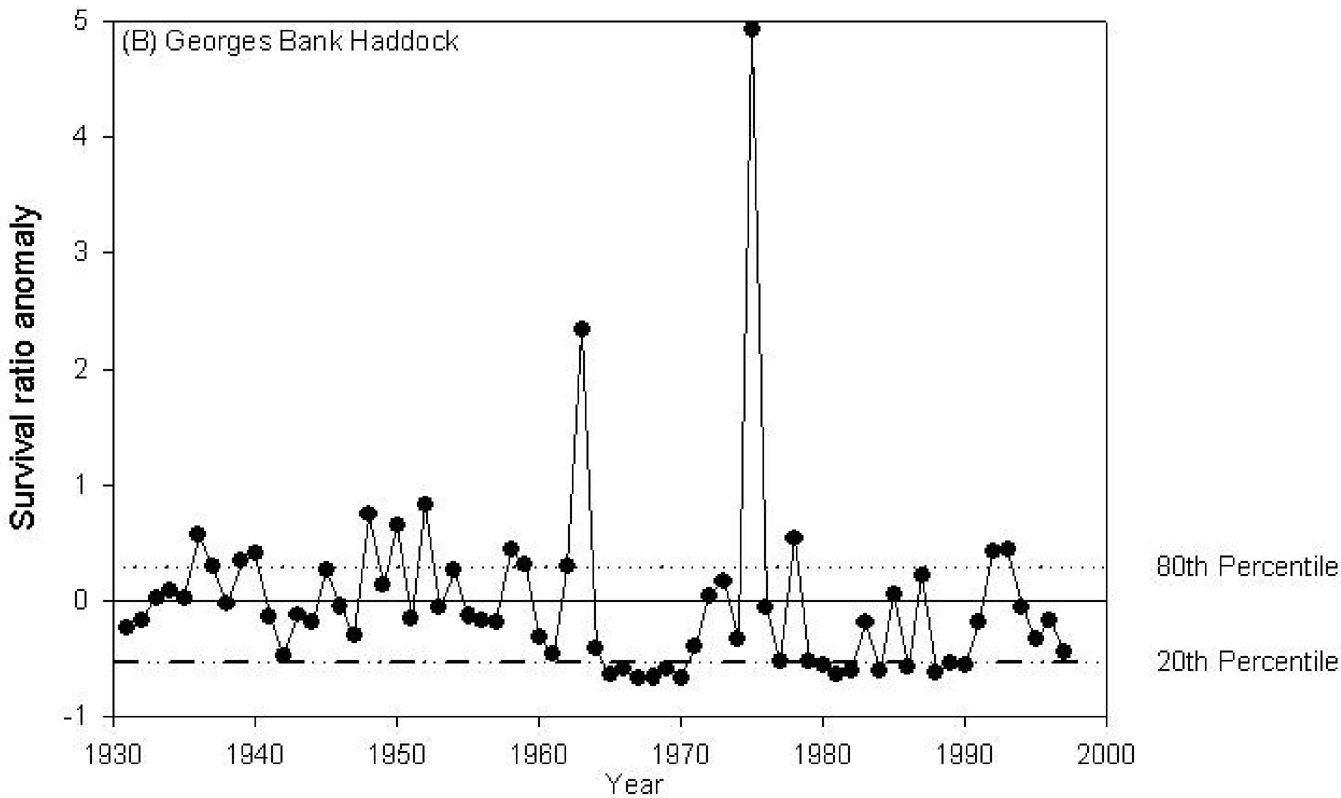


Figure B.24. ***Yellowtail flounder survival ratio anomaly***

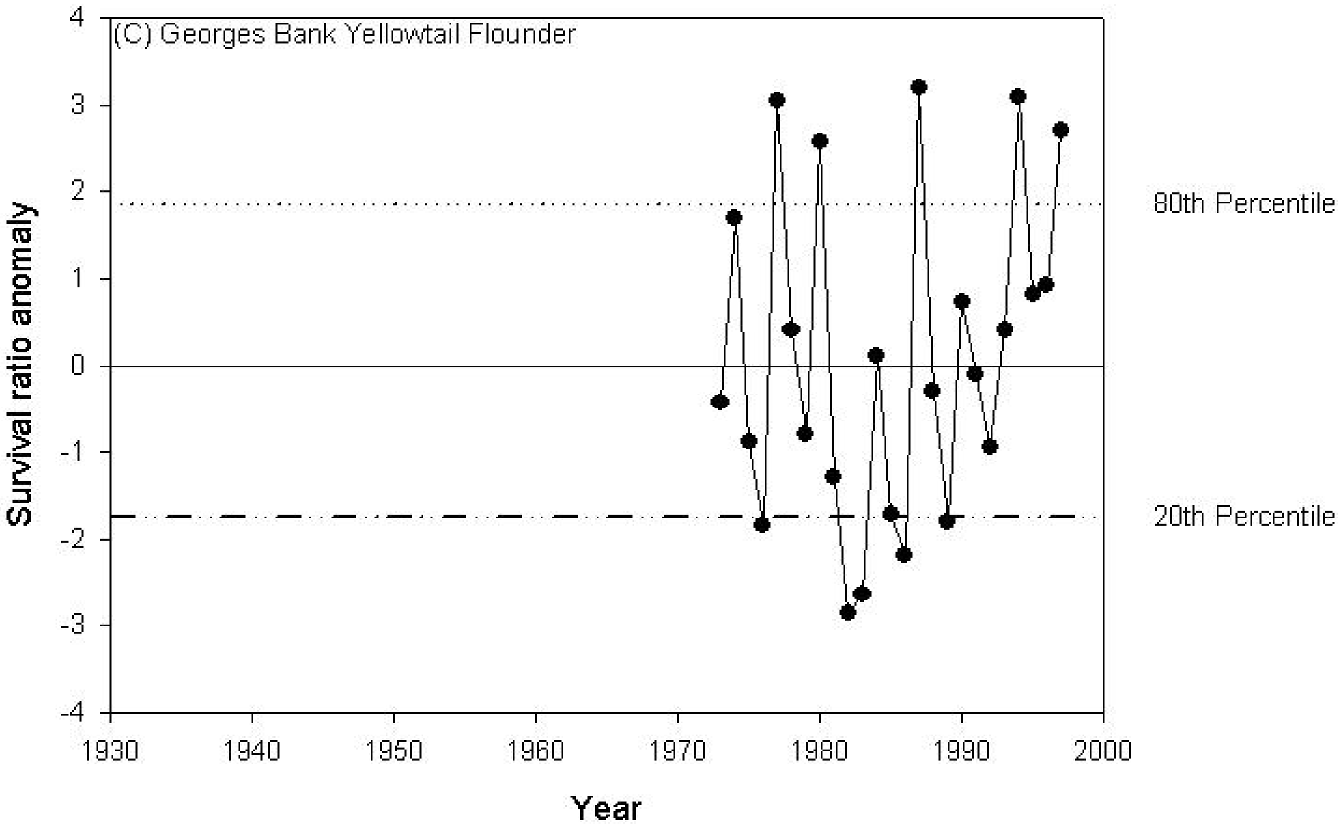


Figure B.25a. ***Total biomass for all from both fall and spring bottom trawl surveys***

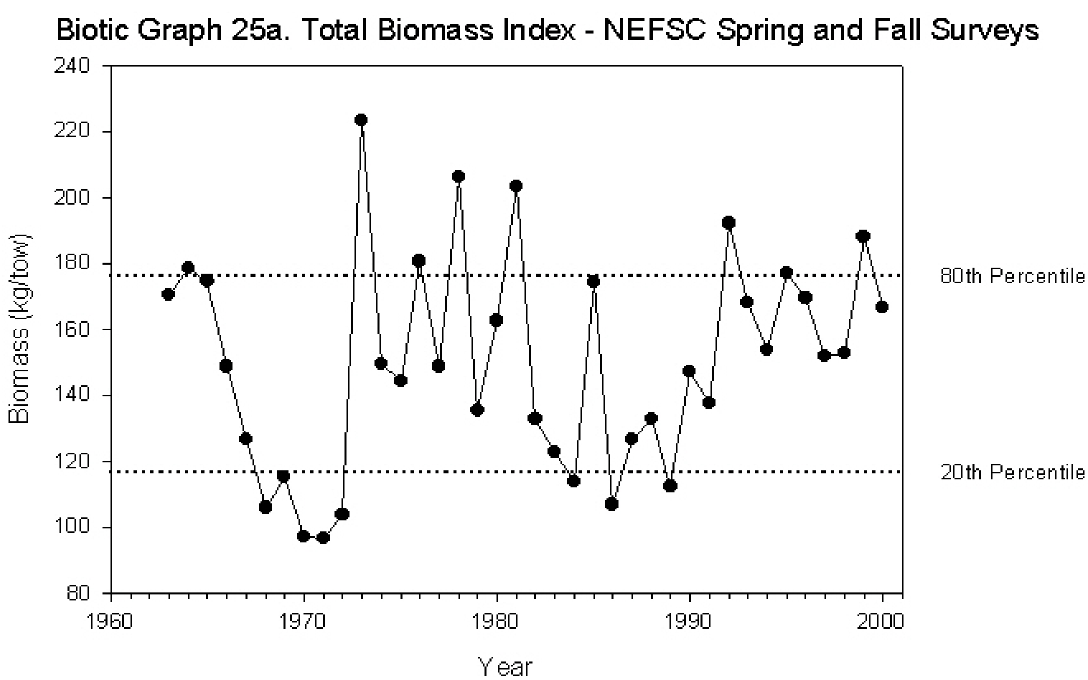


Figure B.25b. ***Total biomass from both fall and spring bottom trawl surveys***

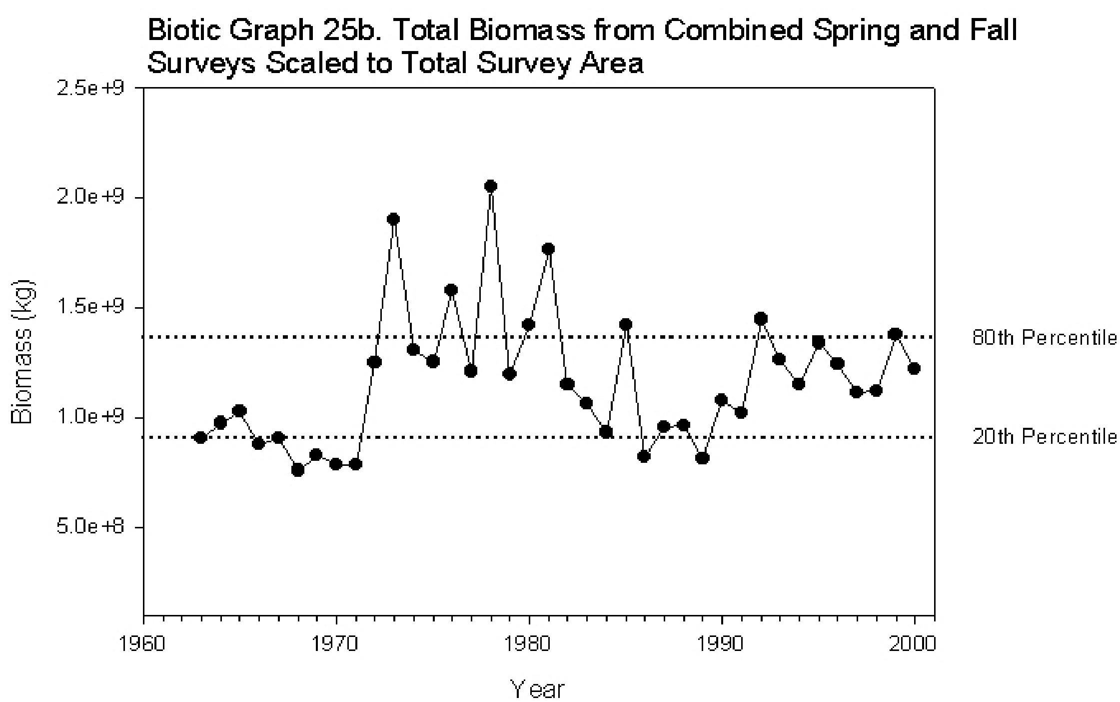


Figure B.26. ***Mean length of all species collected in fall and spring bottom trawl***

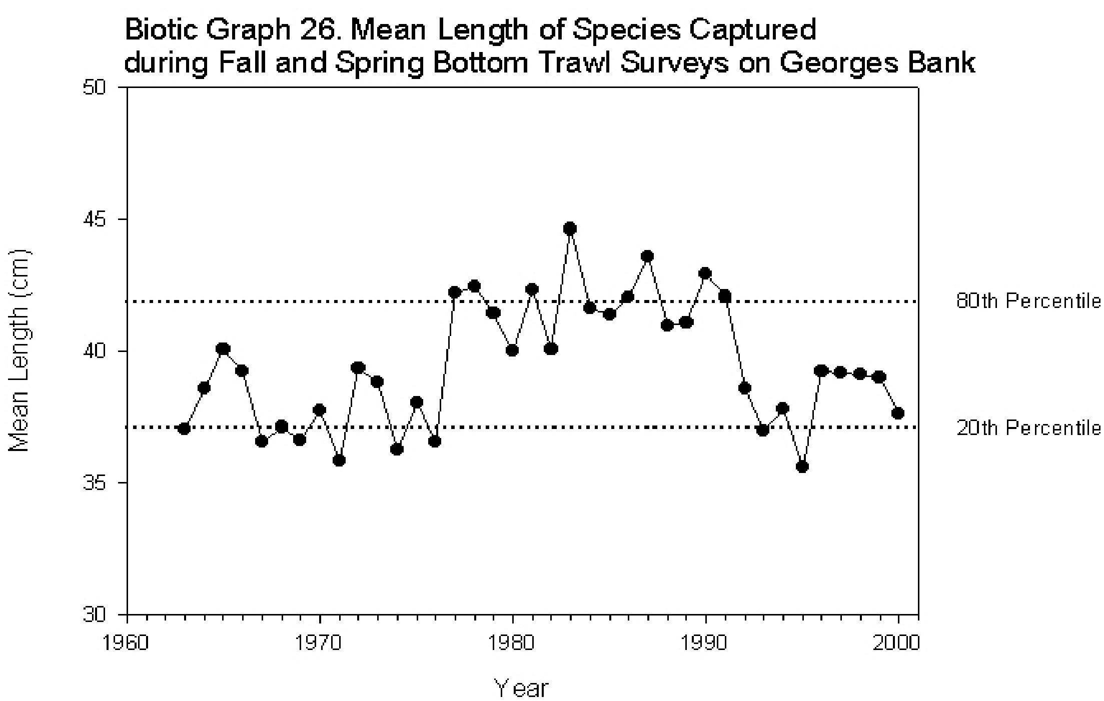


Figure B.27a. ***Abundance of various guilds in fall and spring bottom trawl surveys***

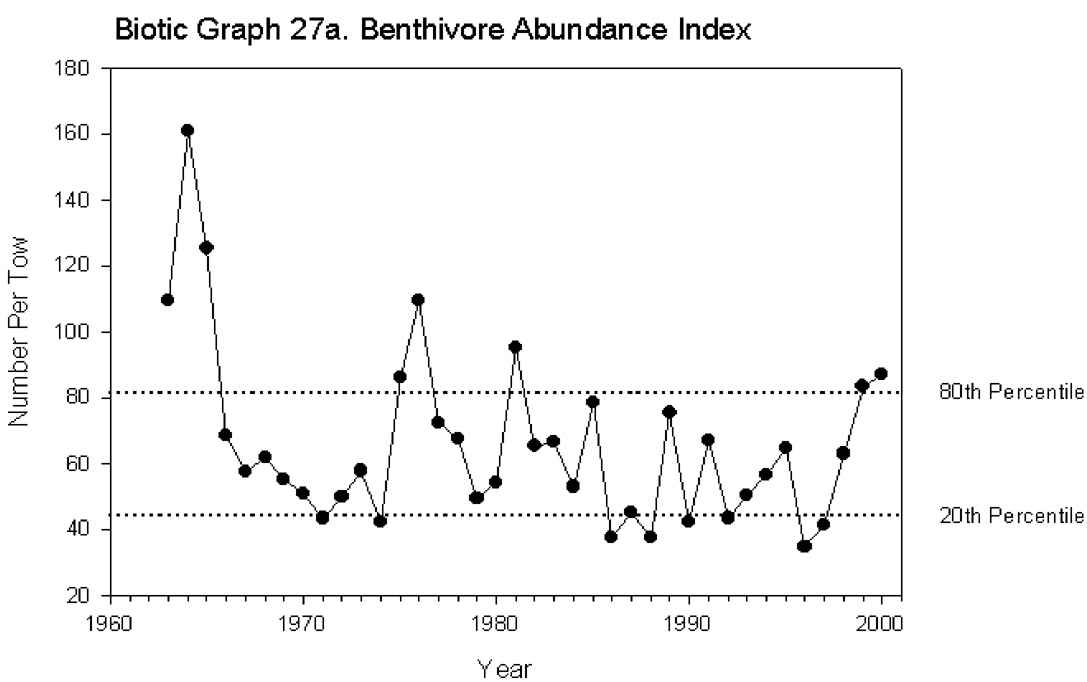


Figure B.27b. ***Abundance of various guilds in fall and spring bottom trawl surveys***

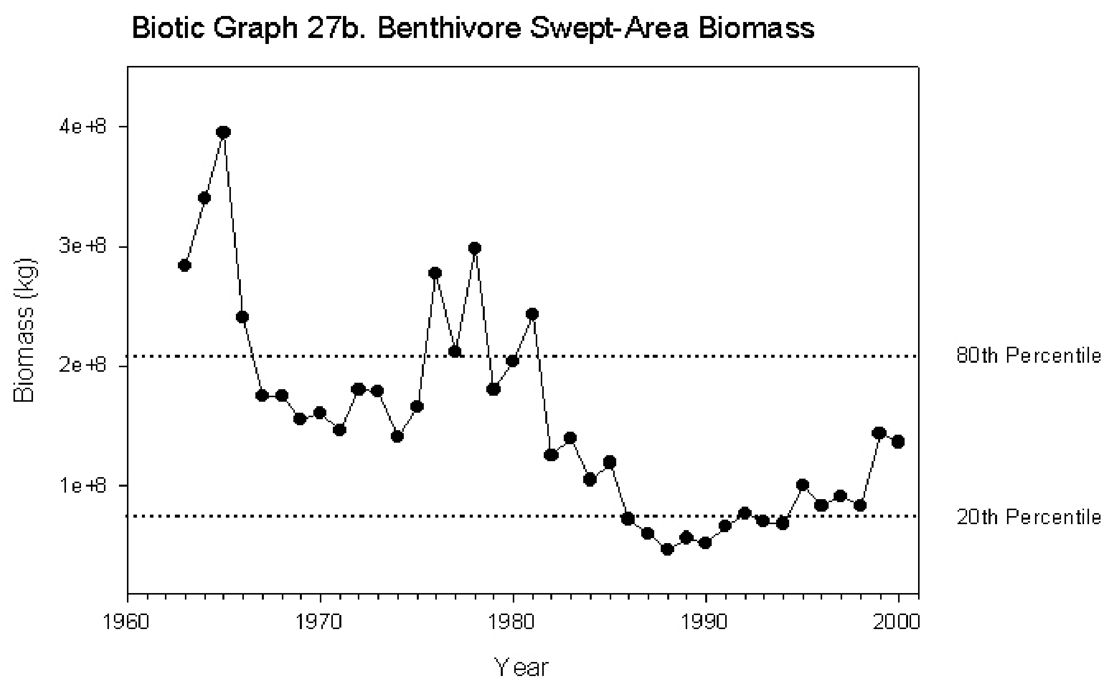


Figure B.27c. ***Abundance of various guilds in fall and spring bottom trawl surveys***

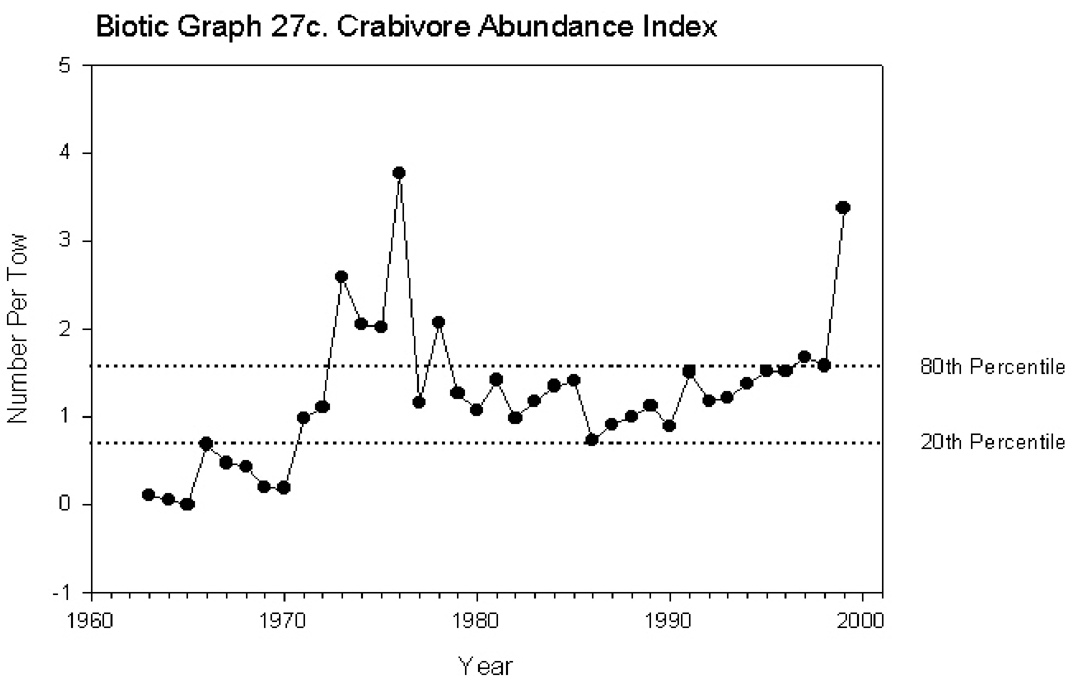


Figure B.27d. ***Abundance of various guilds in fall and spring bottom trawl surveys***

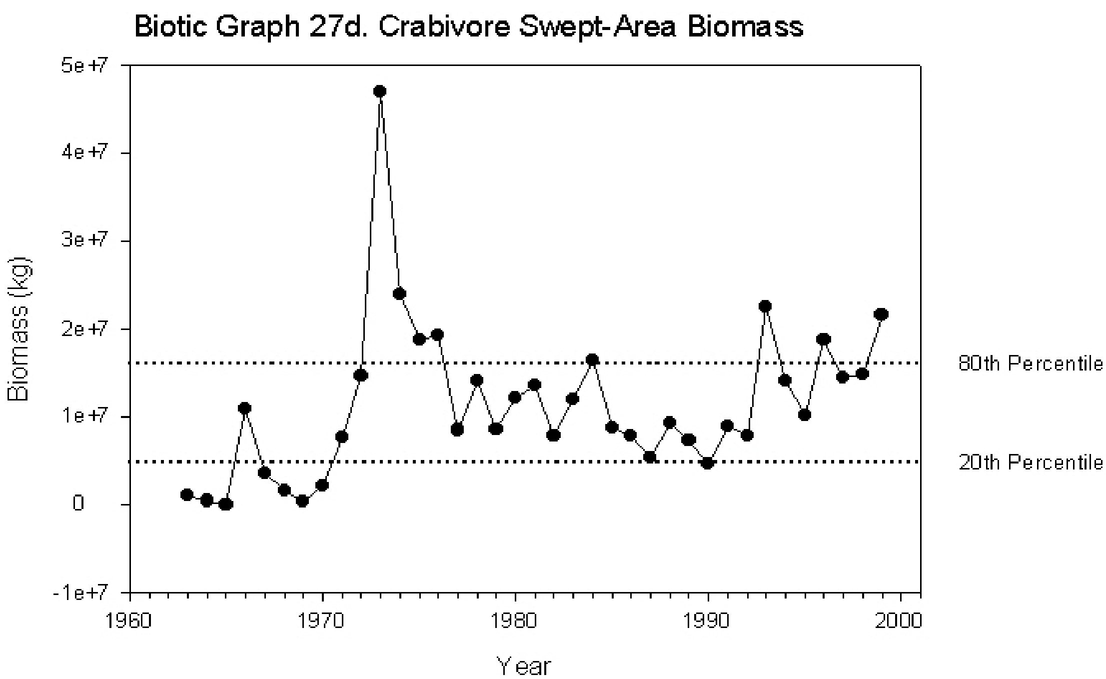


Figure B.27e. ***Abundance of various guilds in fall and spring bottom trawl surveys***

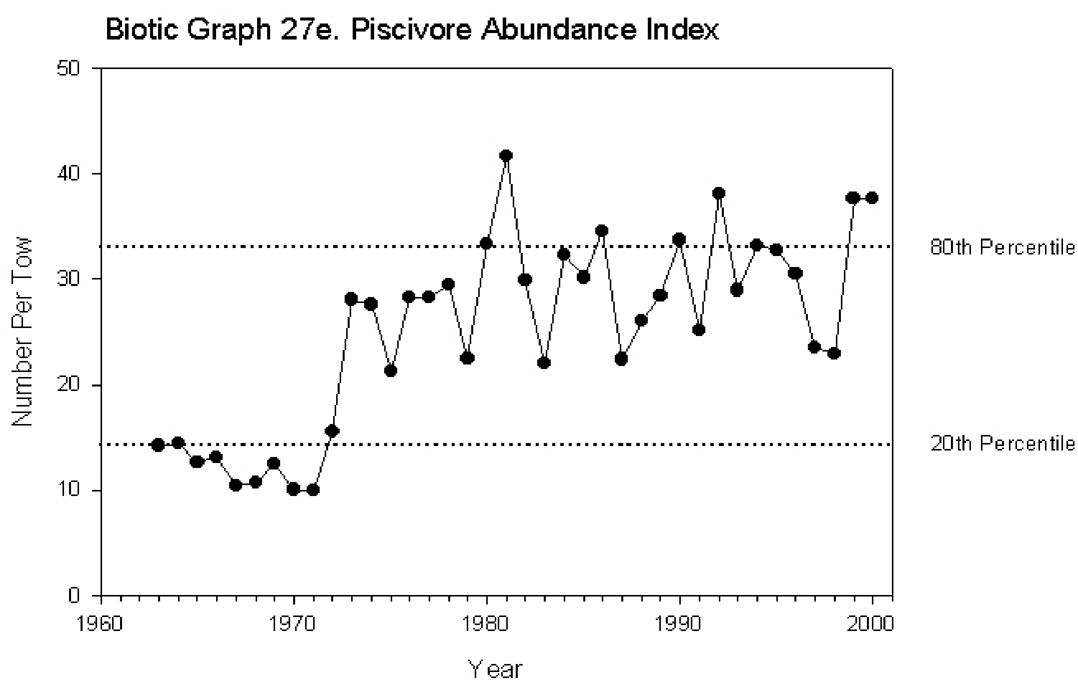


Figure B.27f. ***Abundance of various guilds in fall and spring bottom trawl surveys***

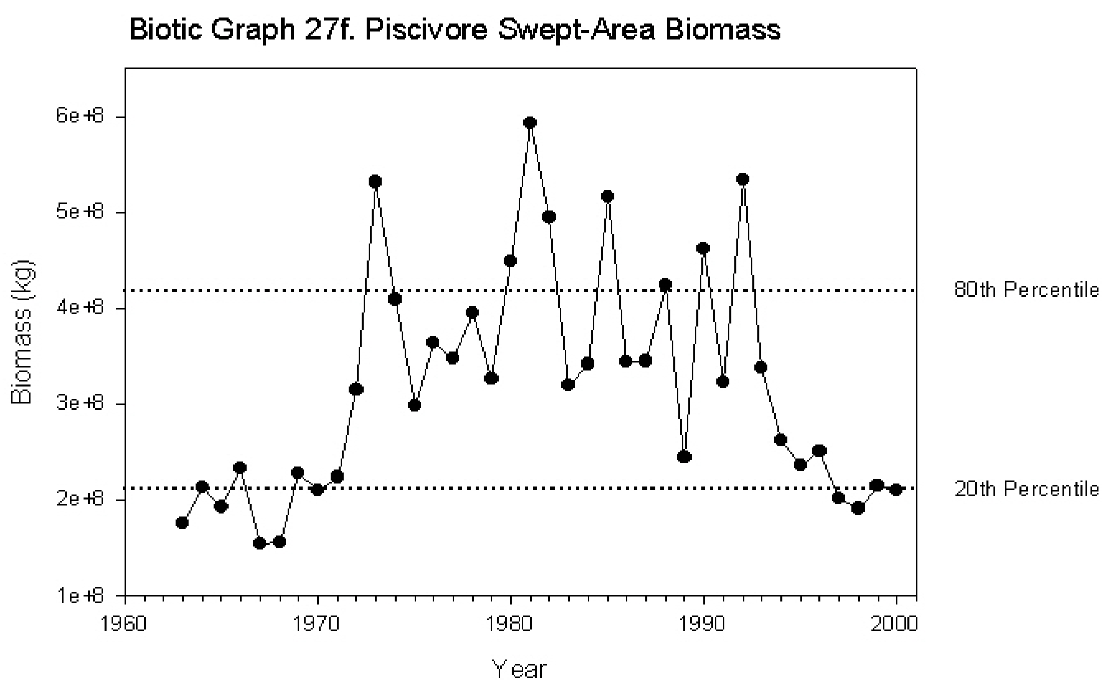


Figure B.27g. ***Abundance of various guilds in fall and spring bottom trawl surveys***

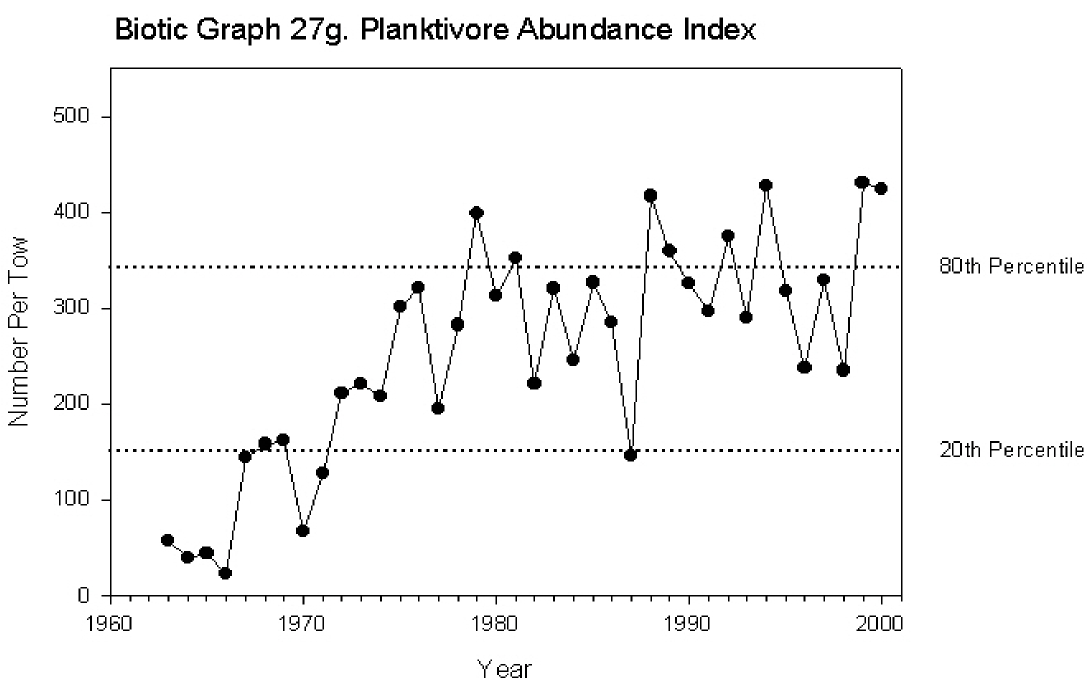


Figure B.27h. ***Abundance of various guilds in fall and spring bottom trawl surveys***

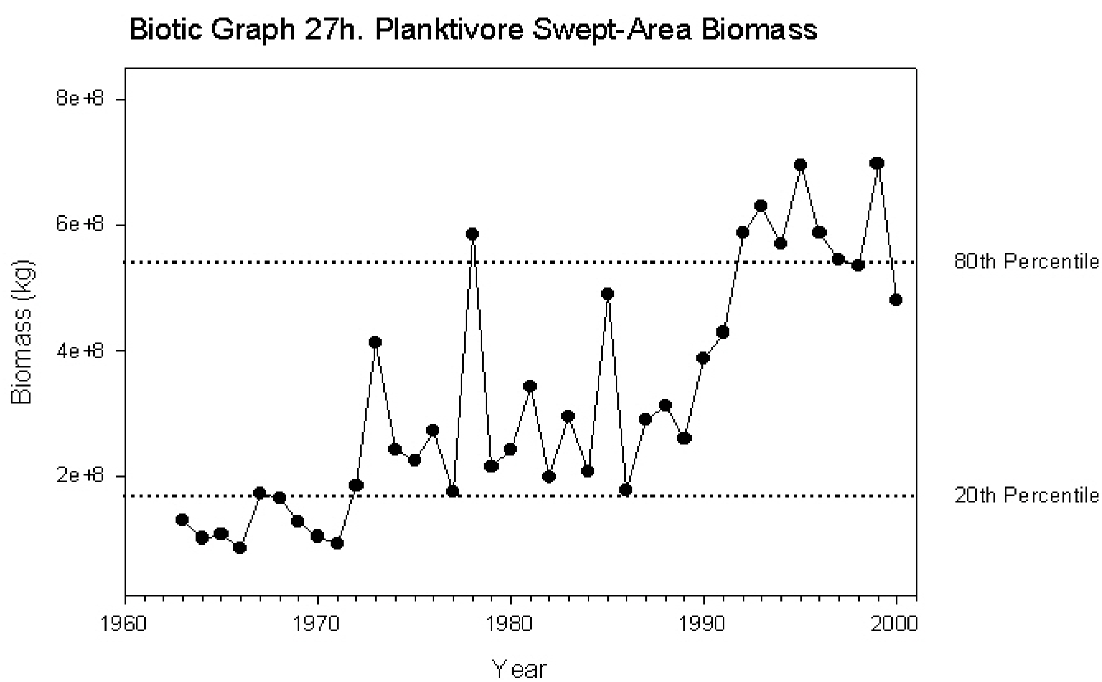


Figure B.27i. ***Abundance of various guilds in fall and spring bottom trawl surveys***

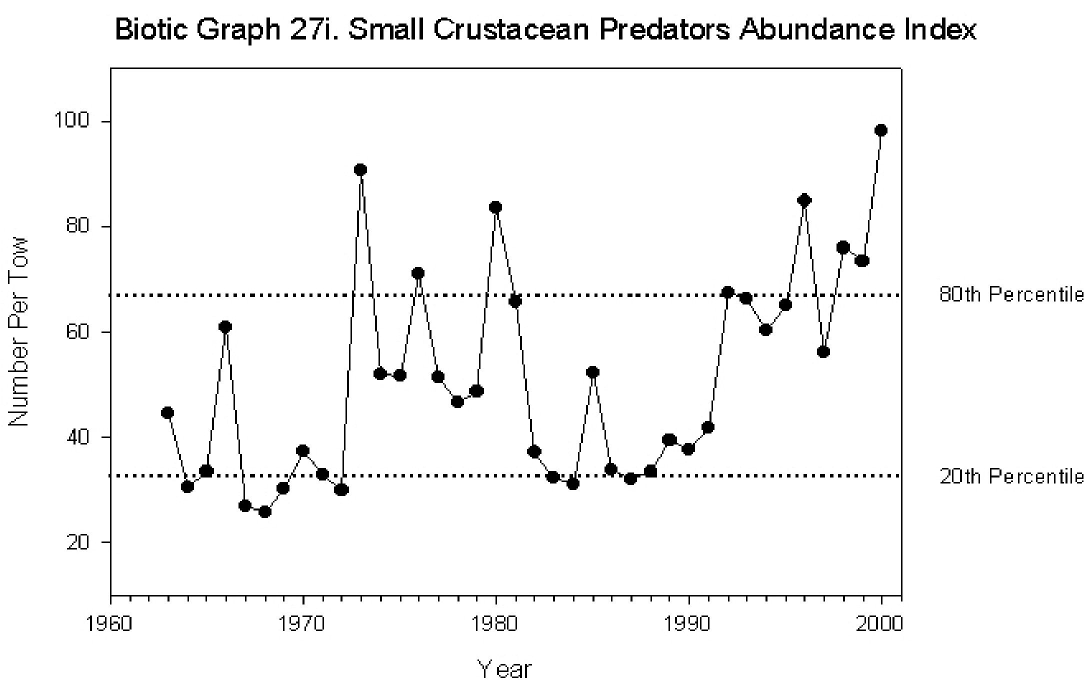


Figure B.27j. ***Abundance of various guilds in fall and spring bottom trawl surveys***

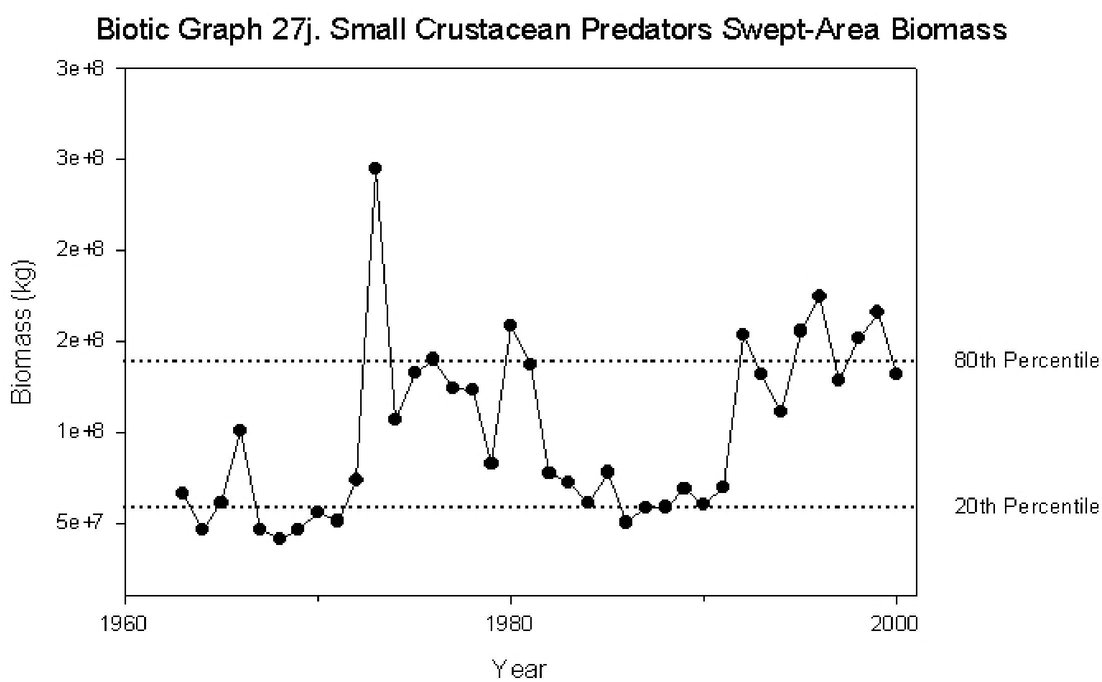


Figure B.27k. ***Abundance of various guilds in fall and spring bottom trawl surveys***

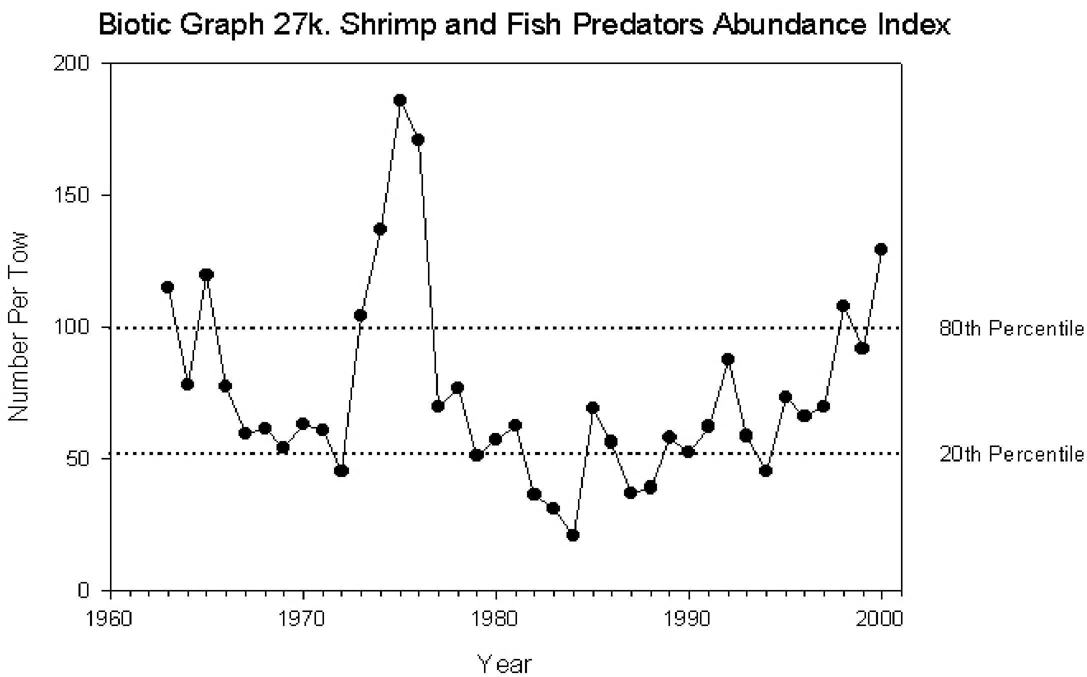


Figure B.27l. ***Abundance of various guilds in fall and spring bottom trawl surveys***

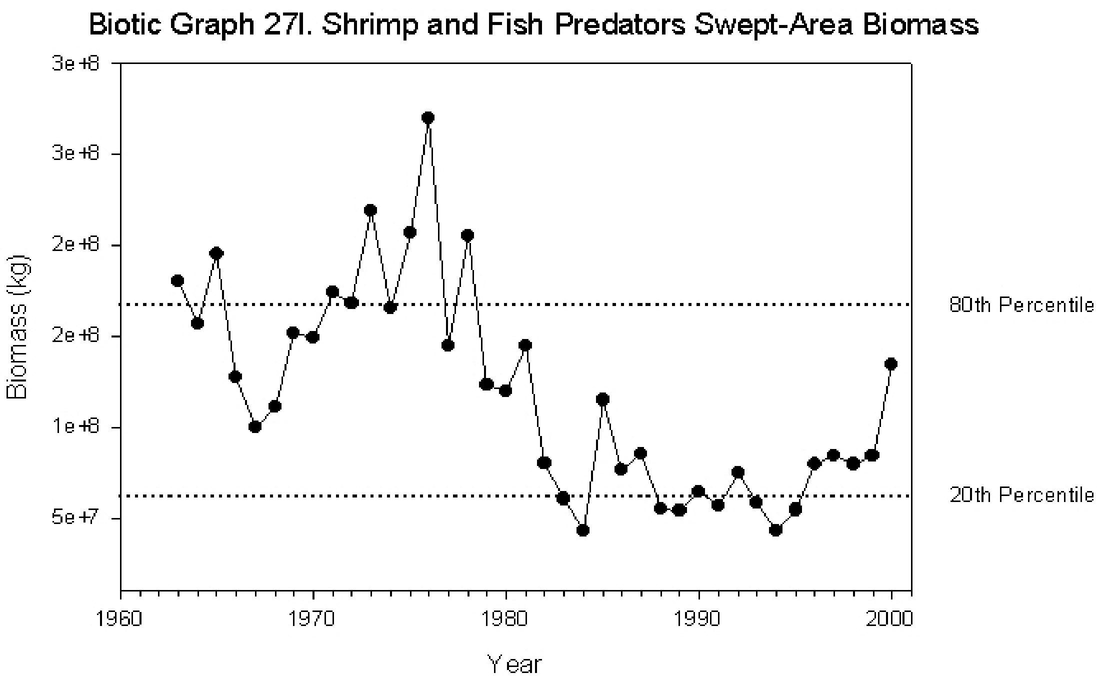


Figure B.28. ***Gulf of Maine total species diversity from bottom trawl survey***

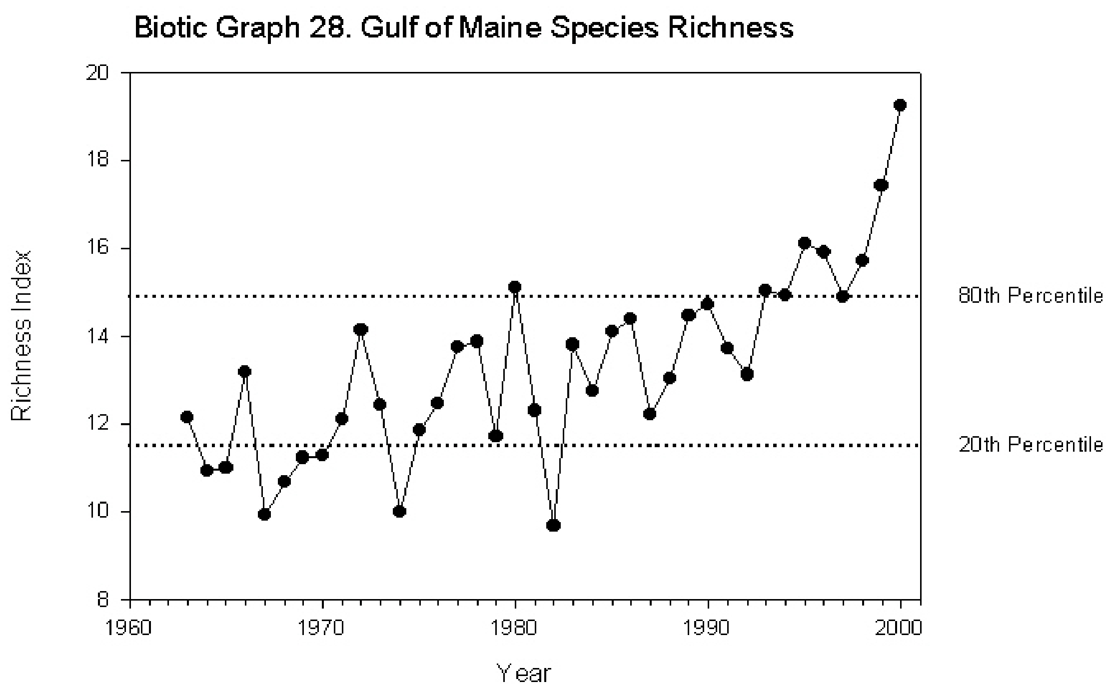


Figure B.29. ***Gulf of Maine abundant species diversity from bottom trawl survey***

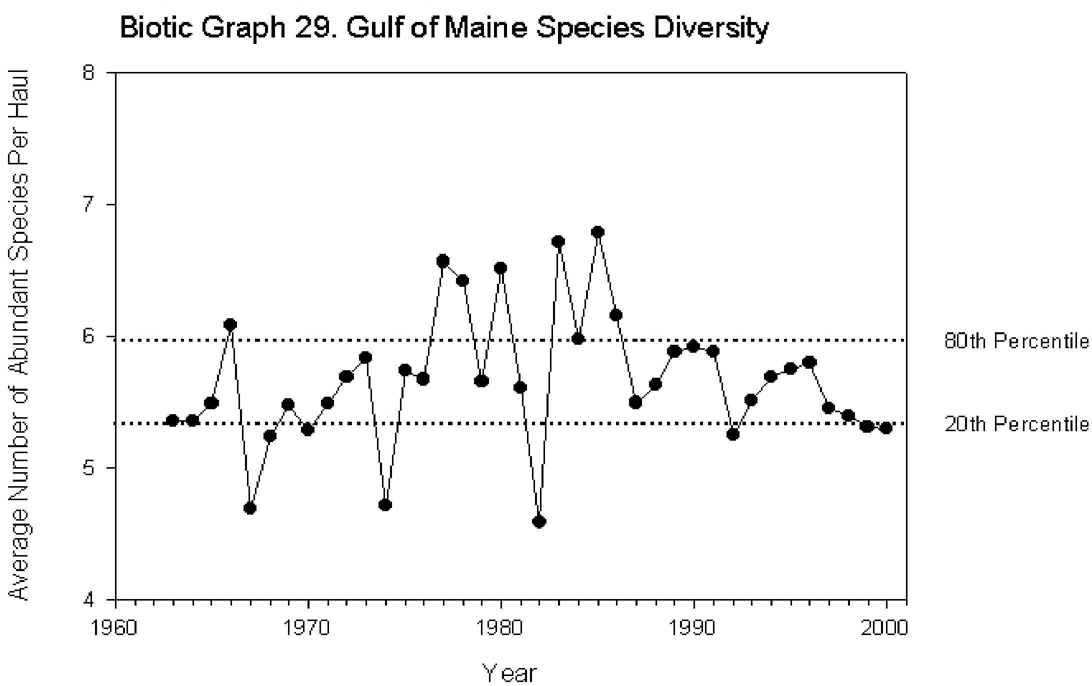


Figure B.30. ***Gulf of Maine species evenness from bottom trawl survey***

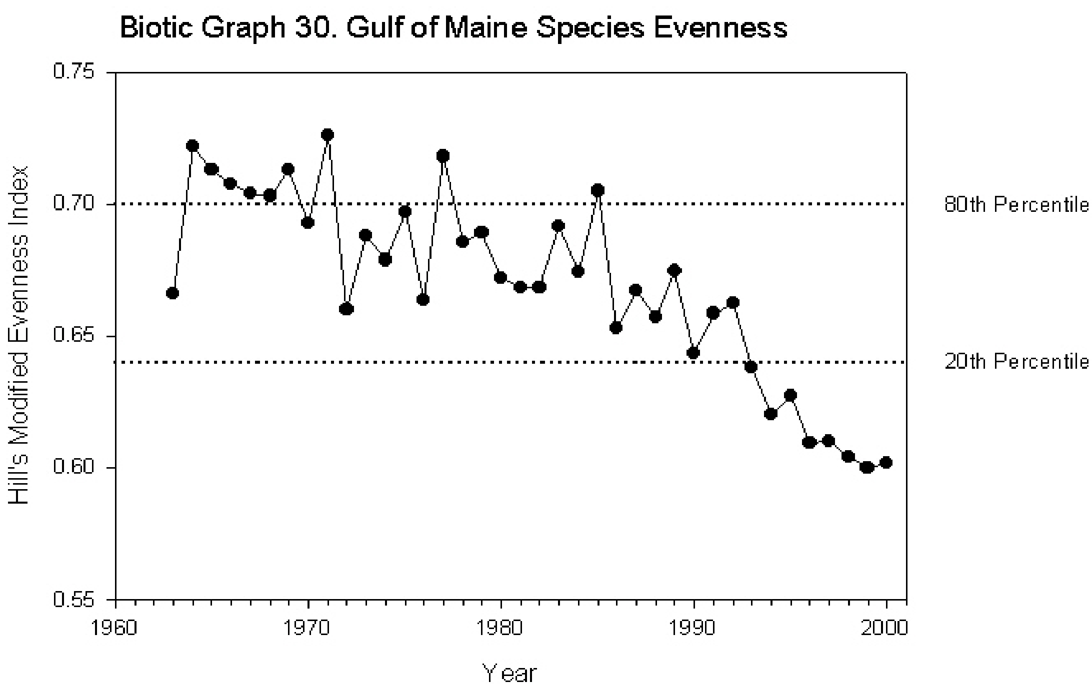


Figure B.31. ***Georges Bank total species diversity from bottom trawl survey***

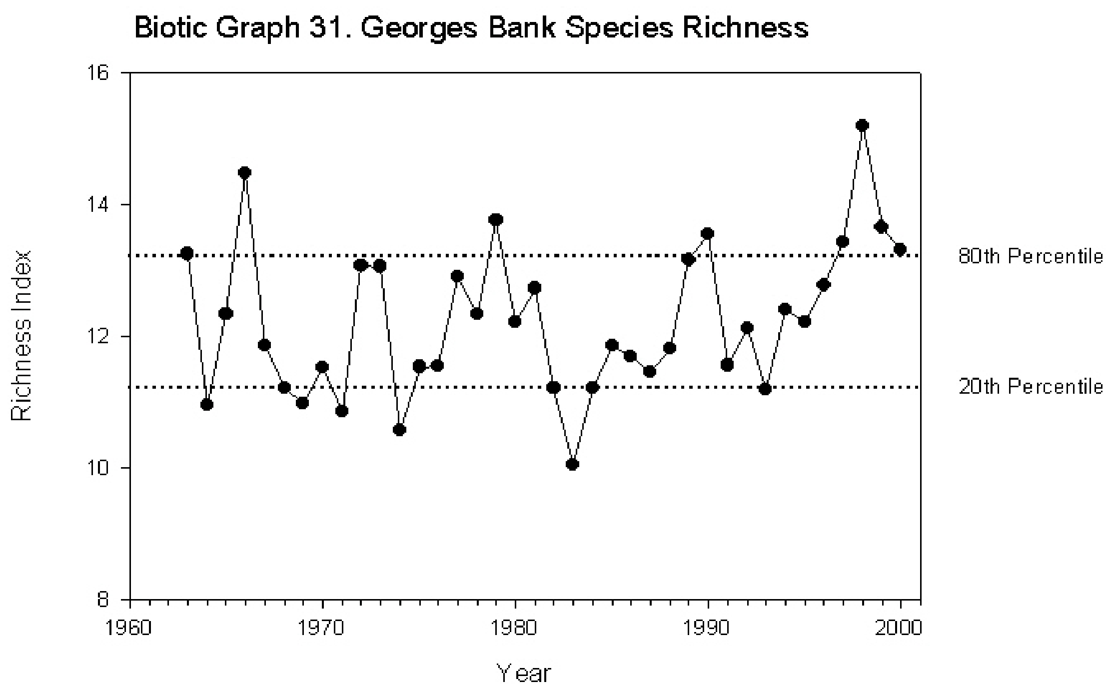


Figure B.32. ***Georges Bank abundant species diversity from bottom trawl surveys***

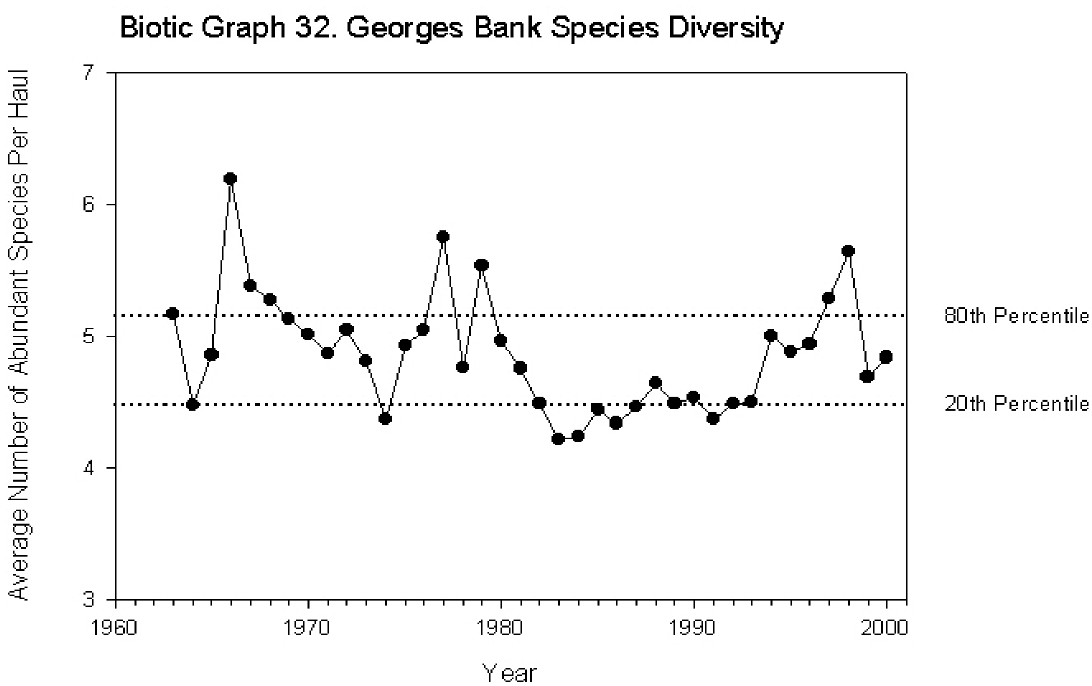


Figure B.33. ***Georges Bank species evenness from bottom trawl surveys***

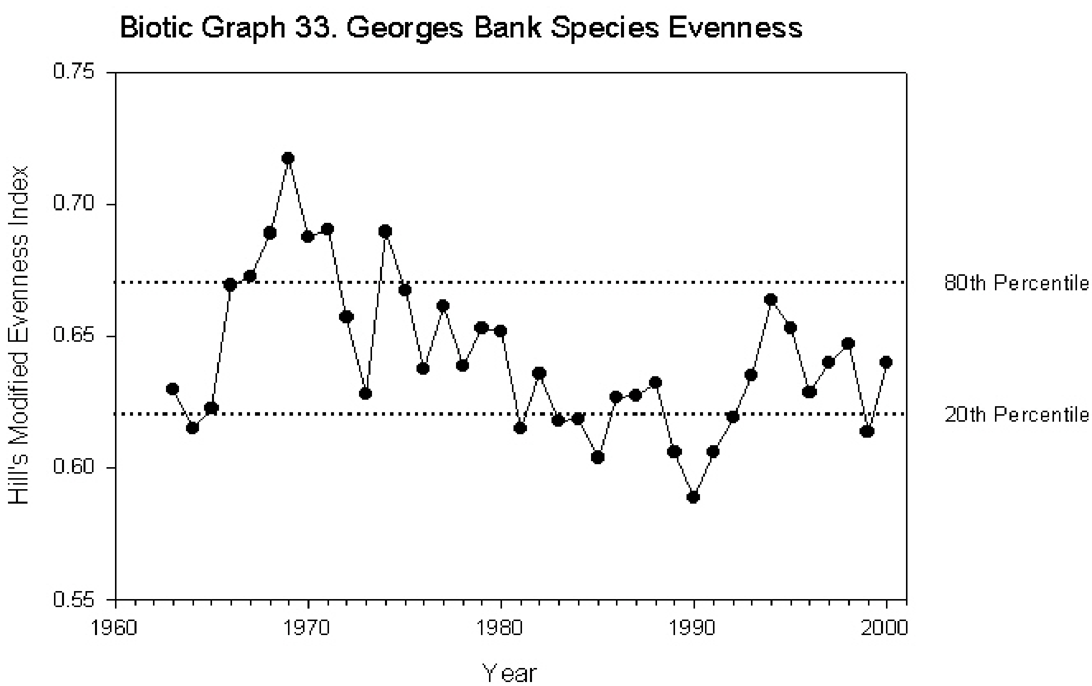


Figure B.34. ***Mid-Atlantic Bight total species diversity from bottom trawl surveys***

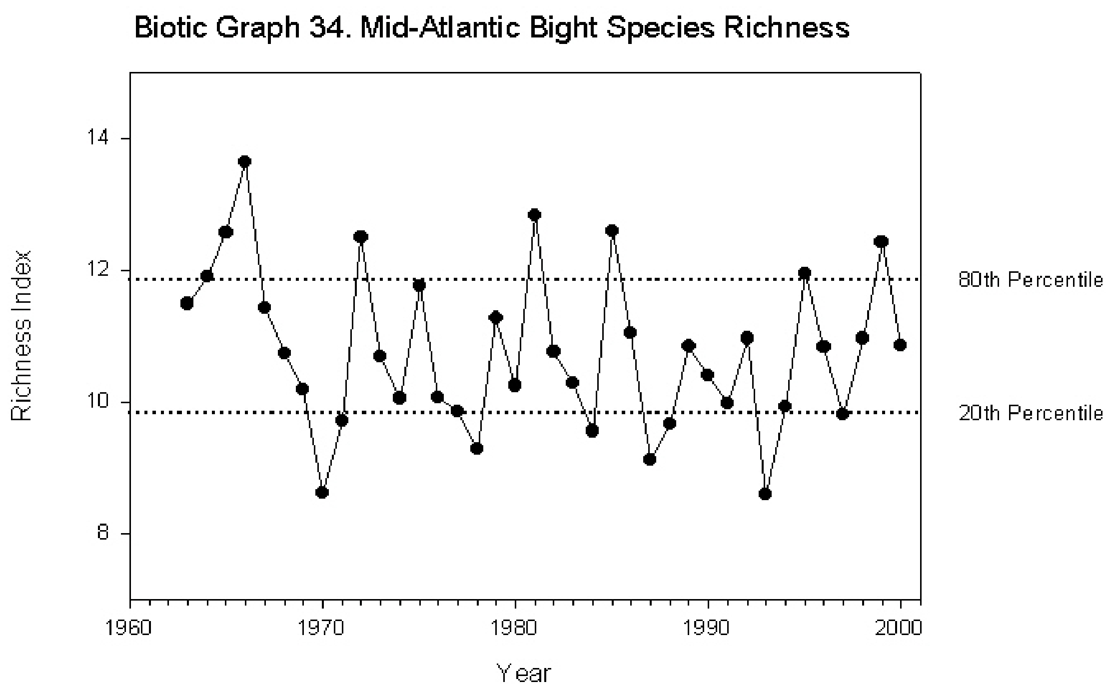


Figure B.35. ***Mid-Atlantic Bight Abundant species diversity from bottom trawl surveys***

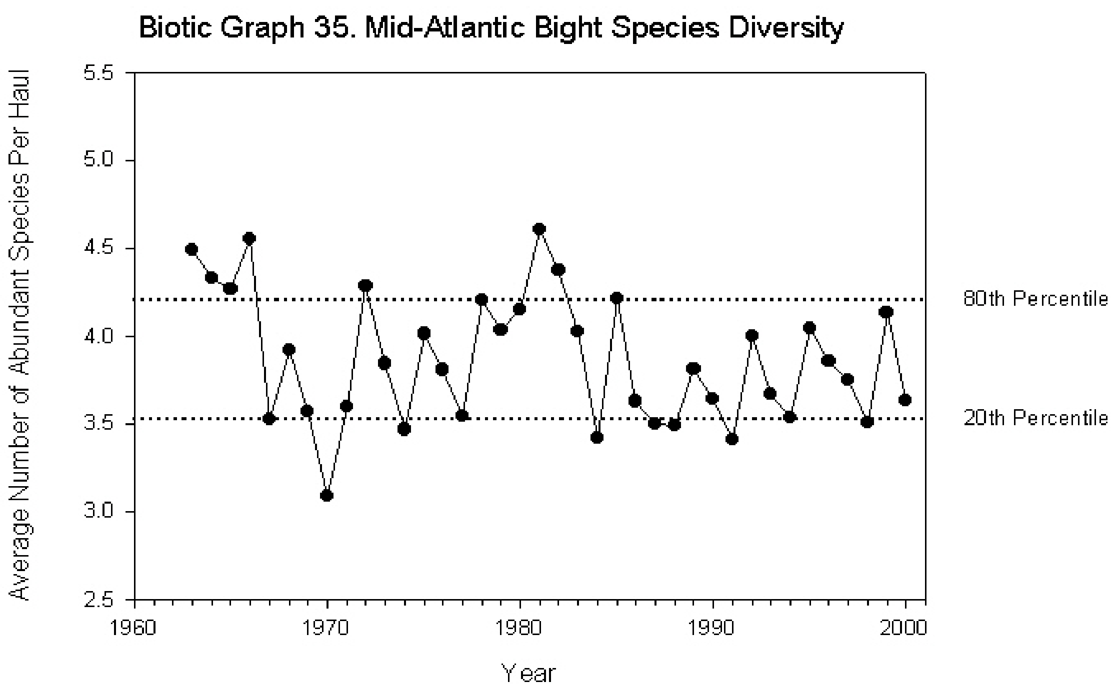


Figure B.36. ***Mid-Atlantic Bight Species evenness from bottom trawl survey***

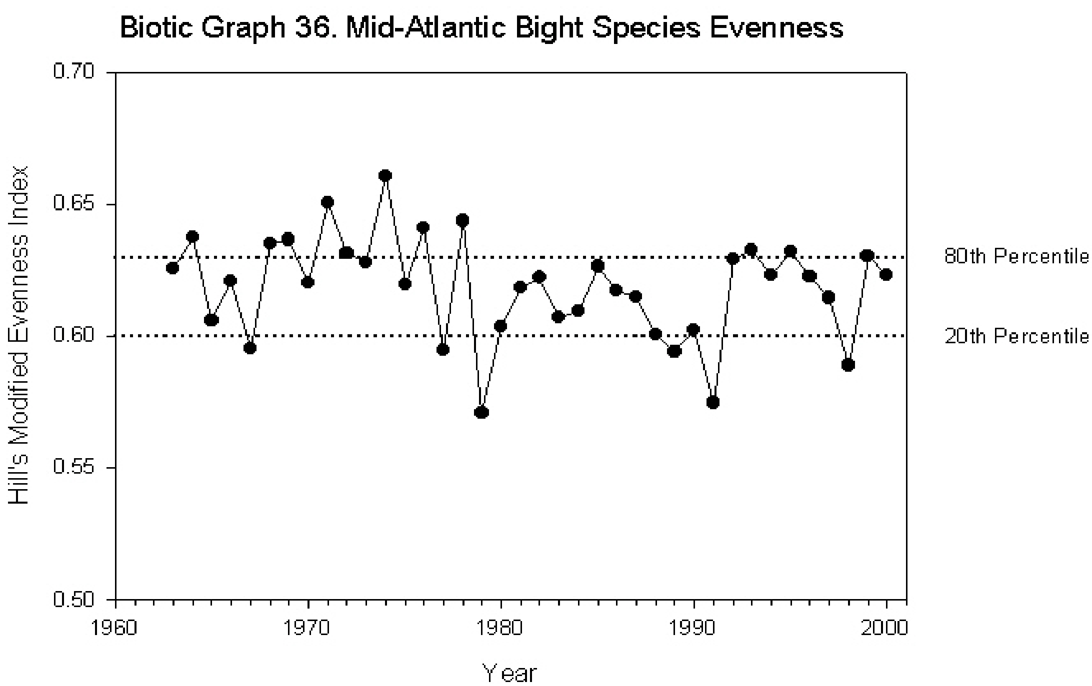


Figure B.37. ***Silver hake linkage density***

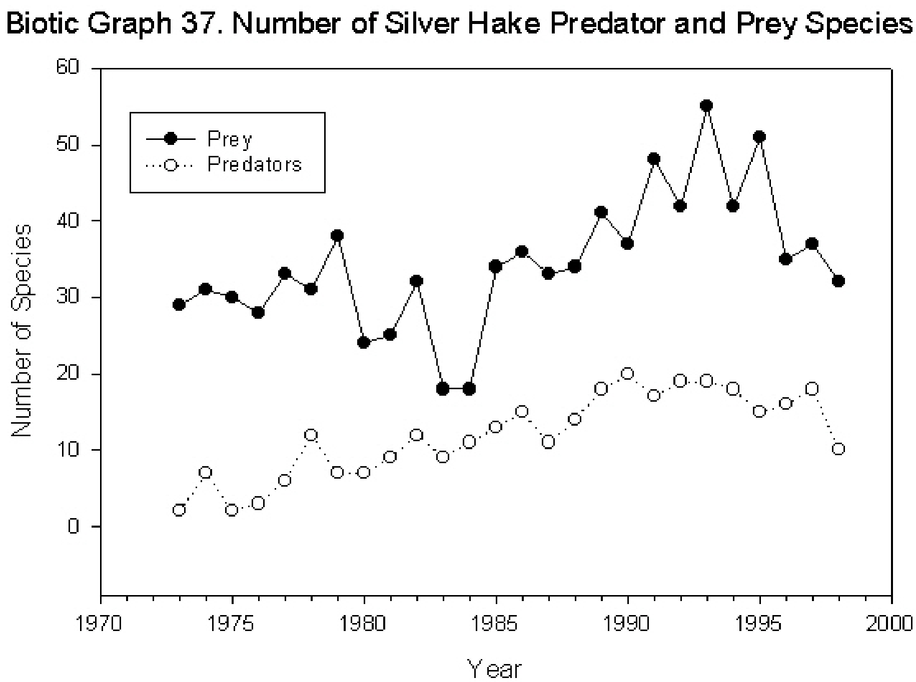


Figure B.38. ***Total consumption by 12 piscivores***

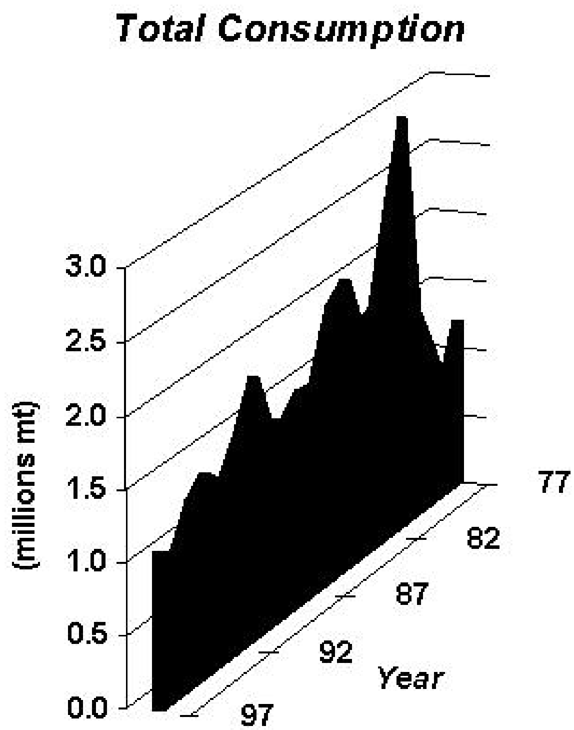


Figure B.39. ***Total fish consumption by six piscivores on Georges Bank***

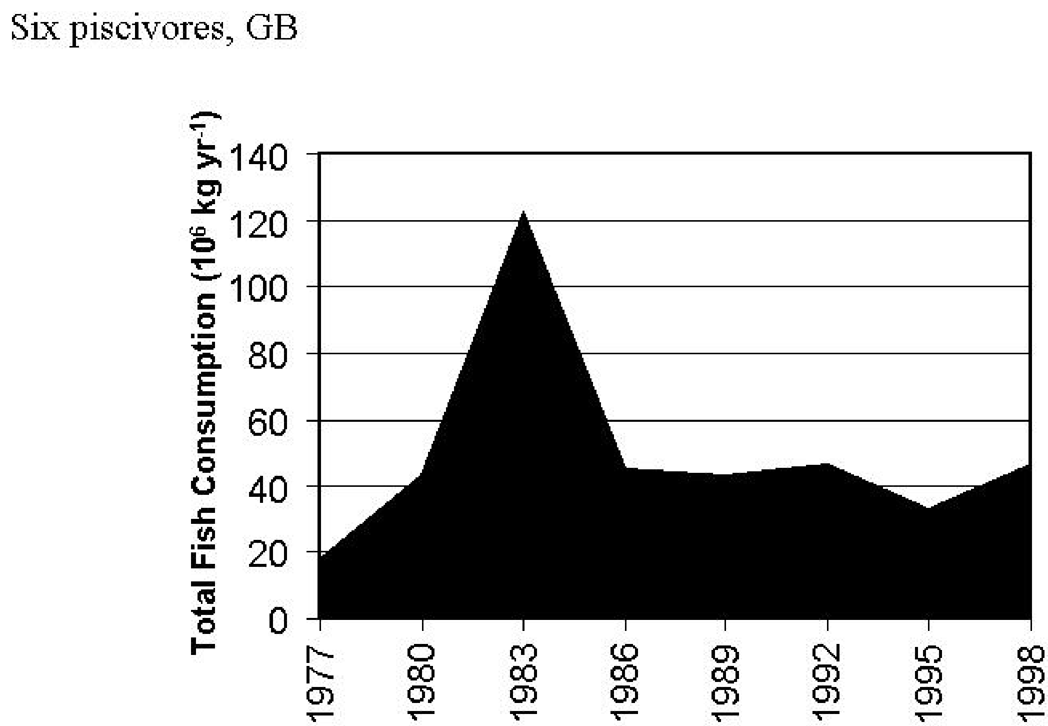


Figure B.40a. ***Consumption of prey species by 12 piscivores***

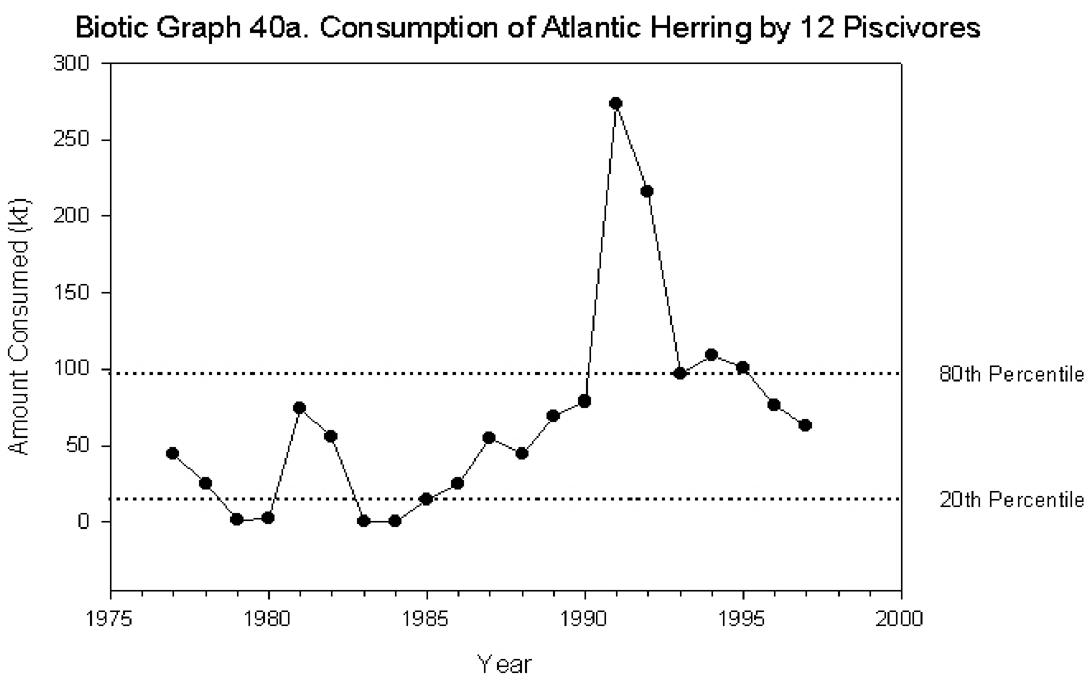


Figure B.40b. ***Consumption of prey species by 12 piscivores***

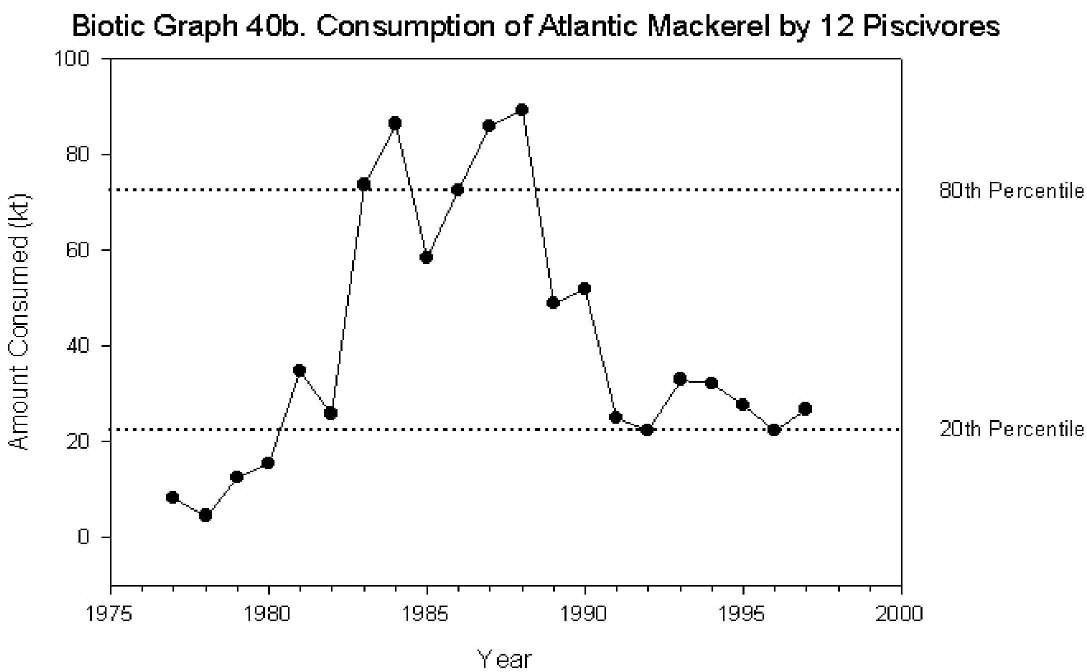


Figure B.40c. ***Consumption of prey species by 12 piscivores***

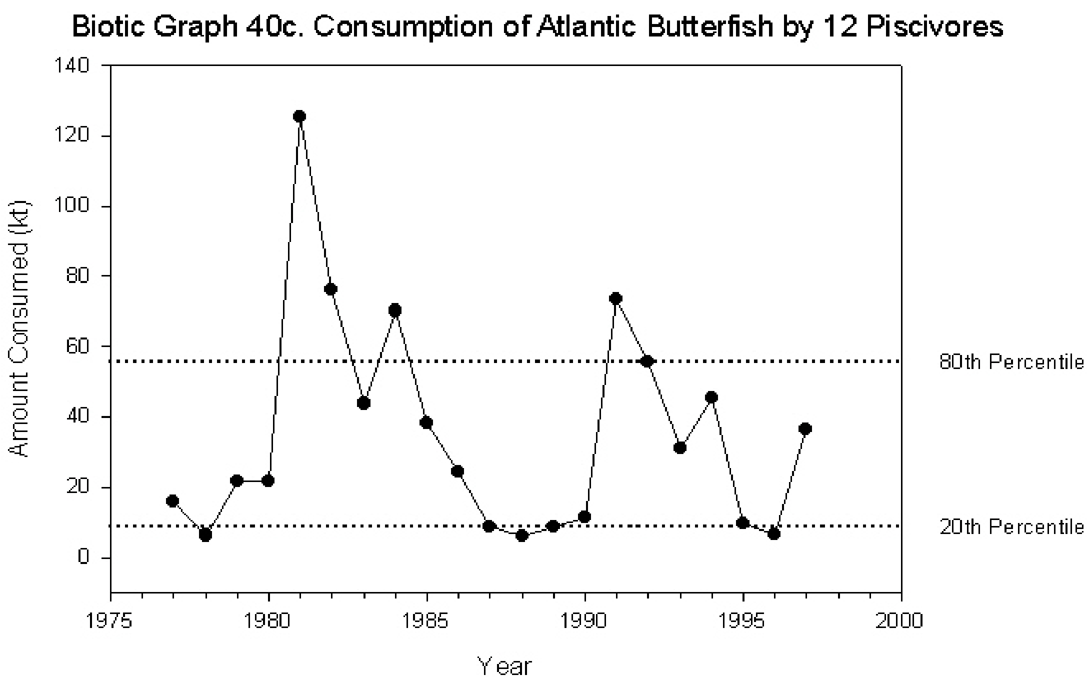


Figure B.40d. ***Consumption of prey species by 12 piscivores***

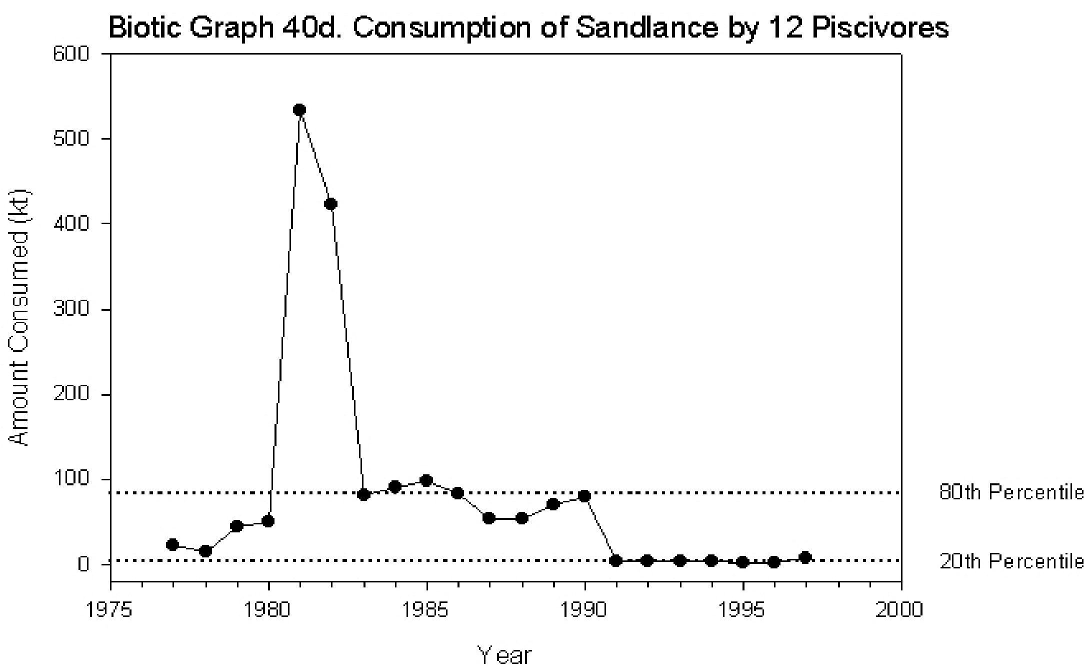


Figure B.40e. ***Consumption of prey species by 12 piscivores***

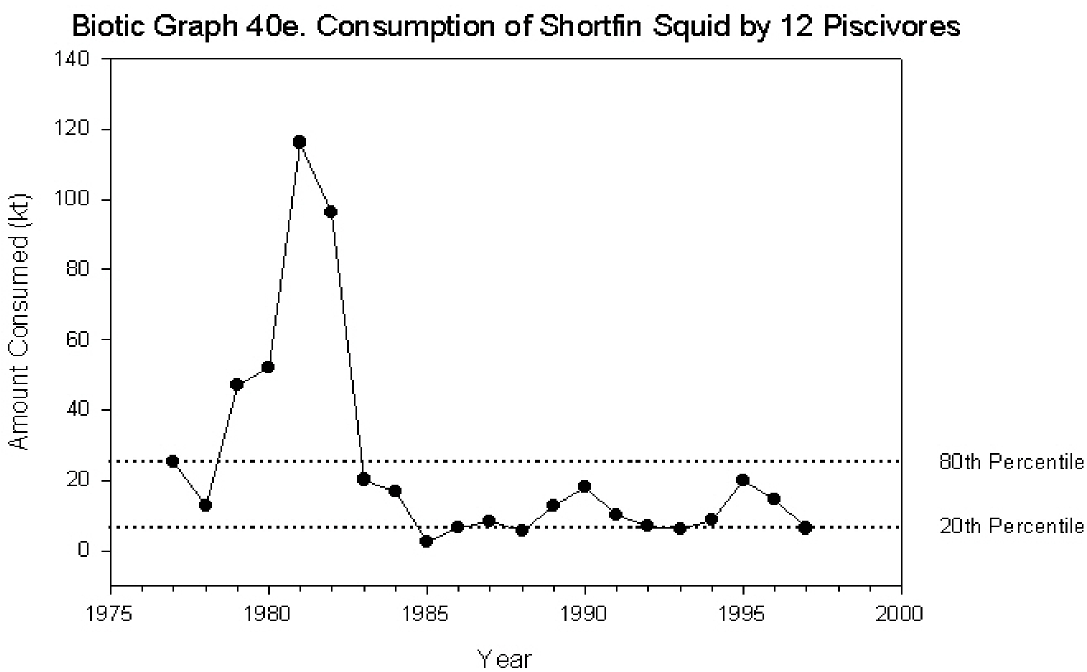


Figure B.40f. ***Consumption of prey species by 12 piscivores***

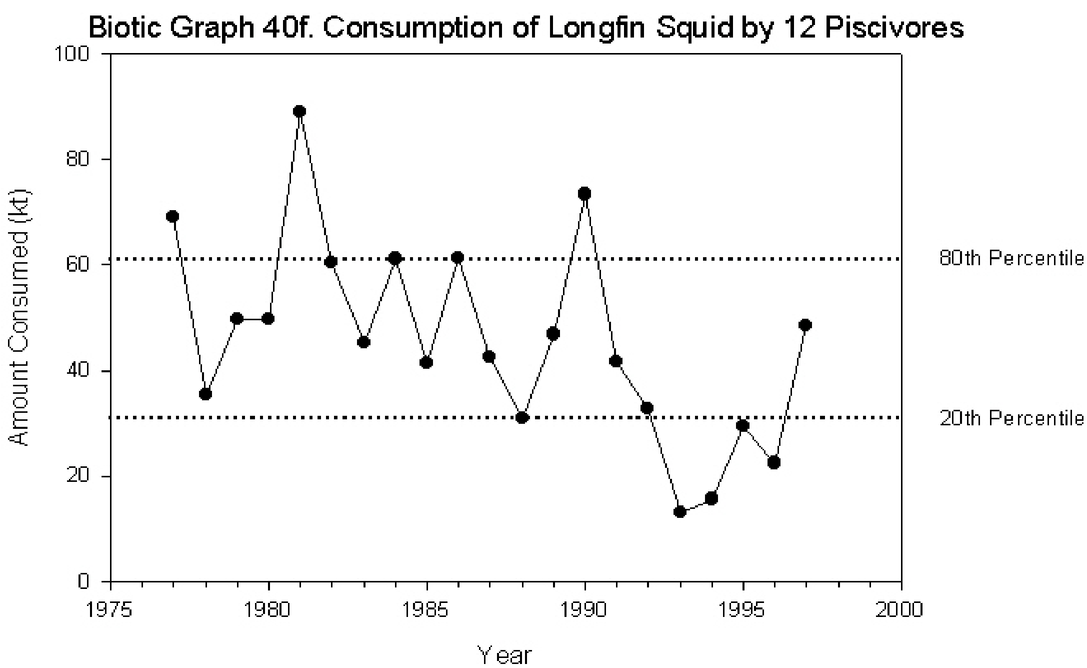


Figure B.41. ***Snapshot of food web for three years in three different decades***

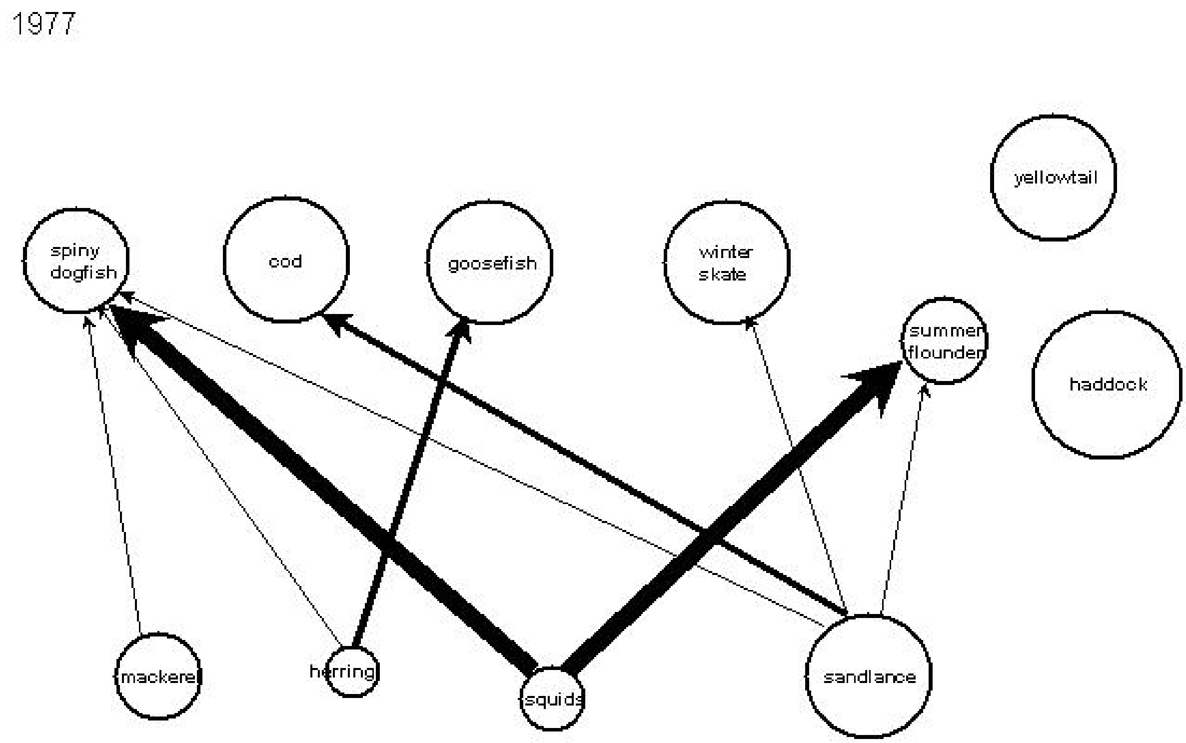


Figure B.42. ***Snapshot of food web for three years in three different decades***

1987

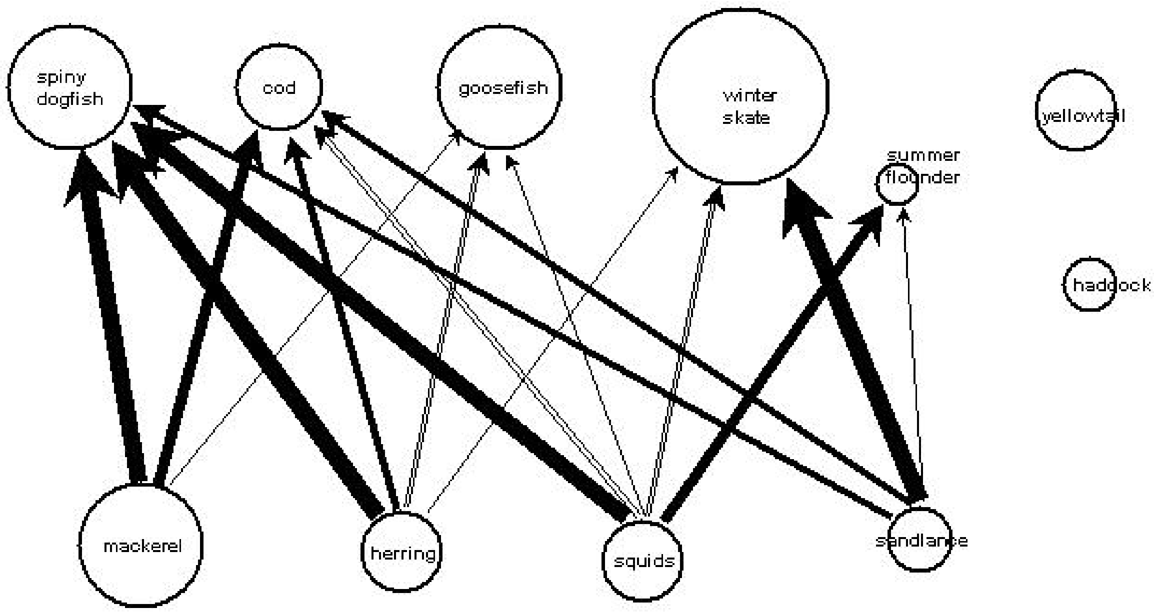


Figure B.43. ***Snapshot of food web for three years in three different decades***

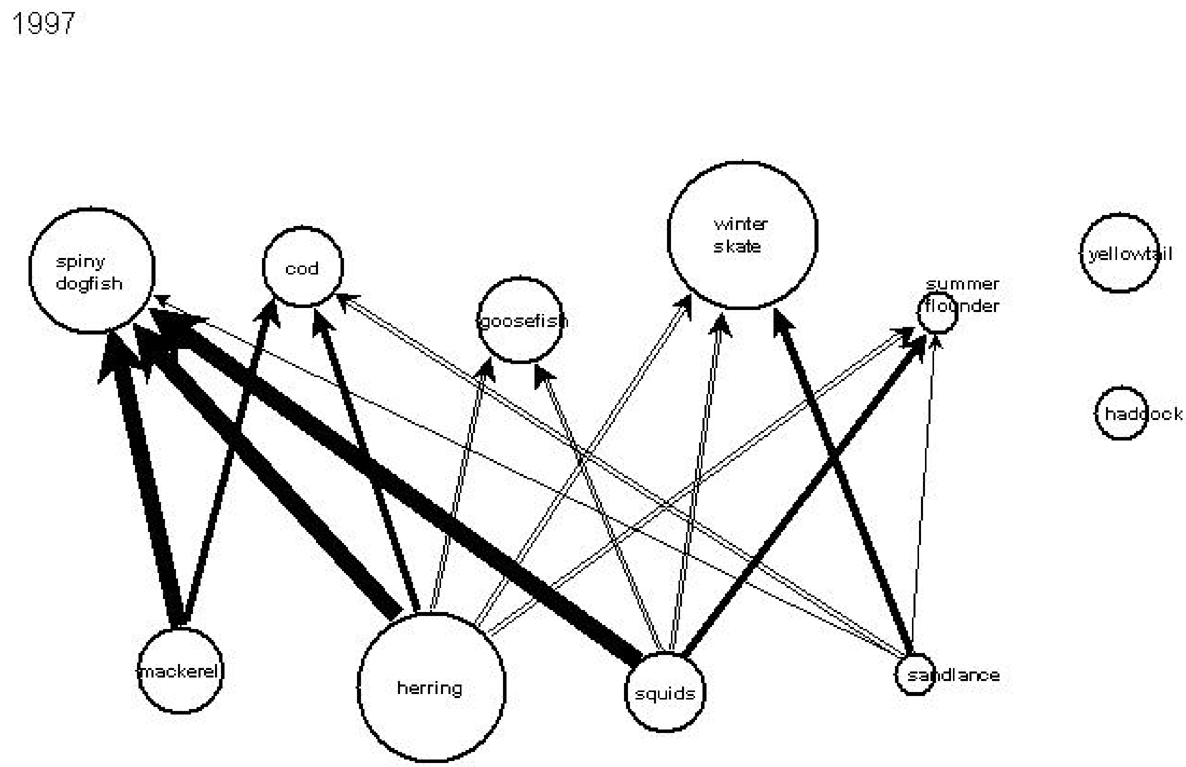


Figure B.44. ***Fish consumption and % fish in diet of cod***

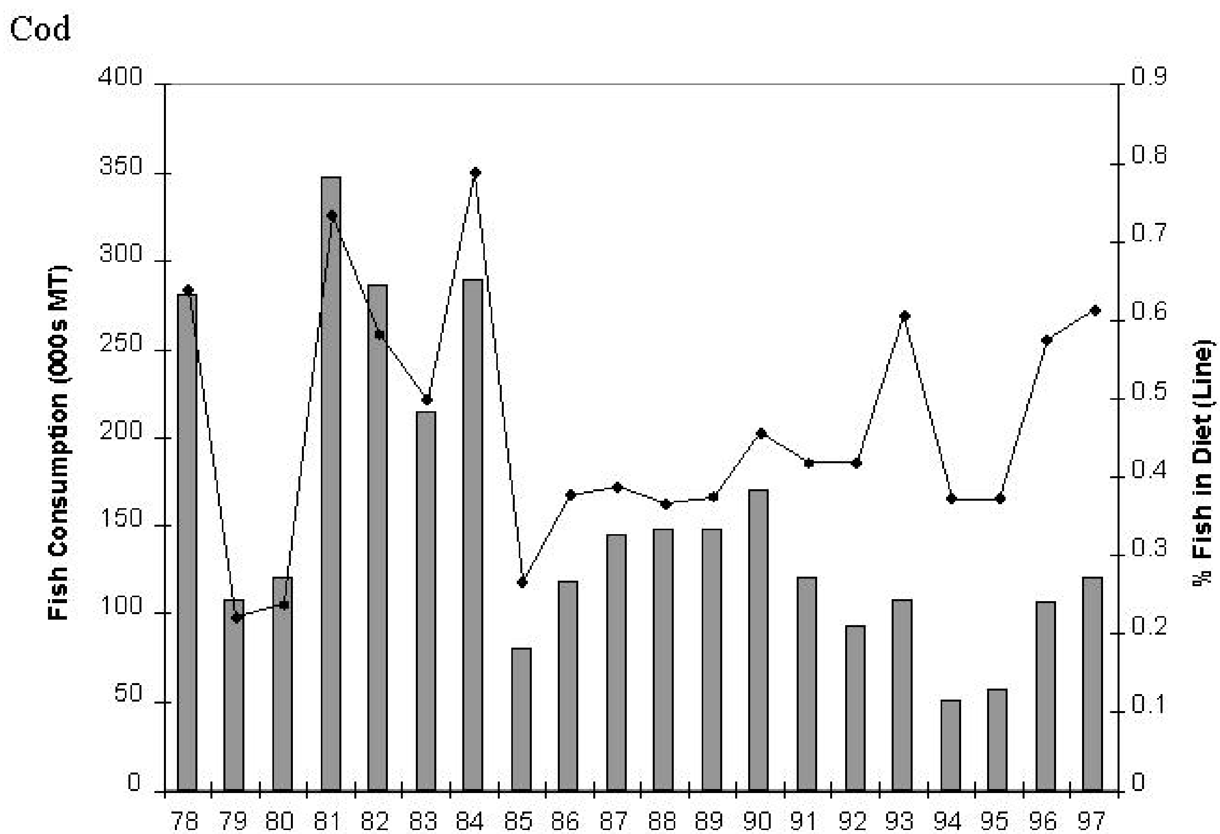


Figure B.45. ***Fish consumption by cod at age***

Cod

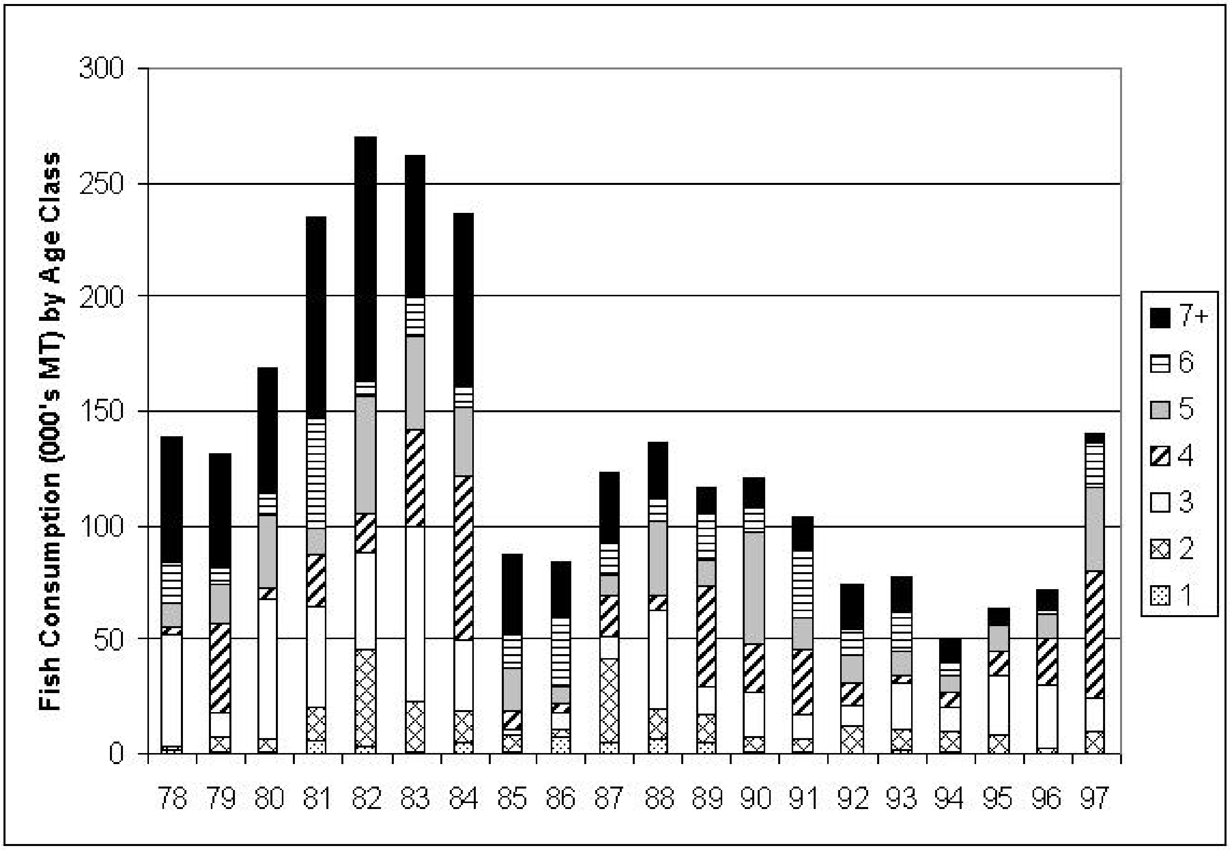


Figure B.46. ***Cod % diet composition of major fish prey***

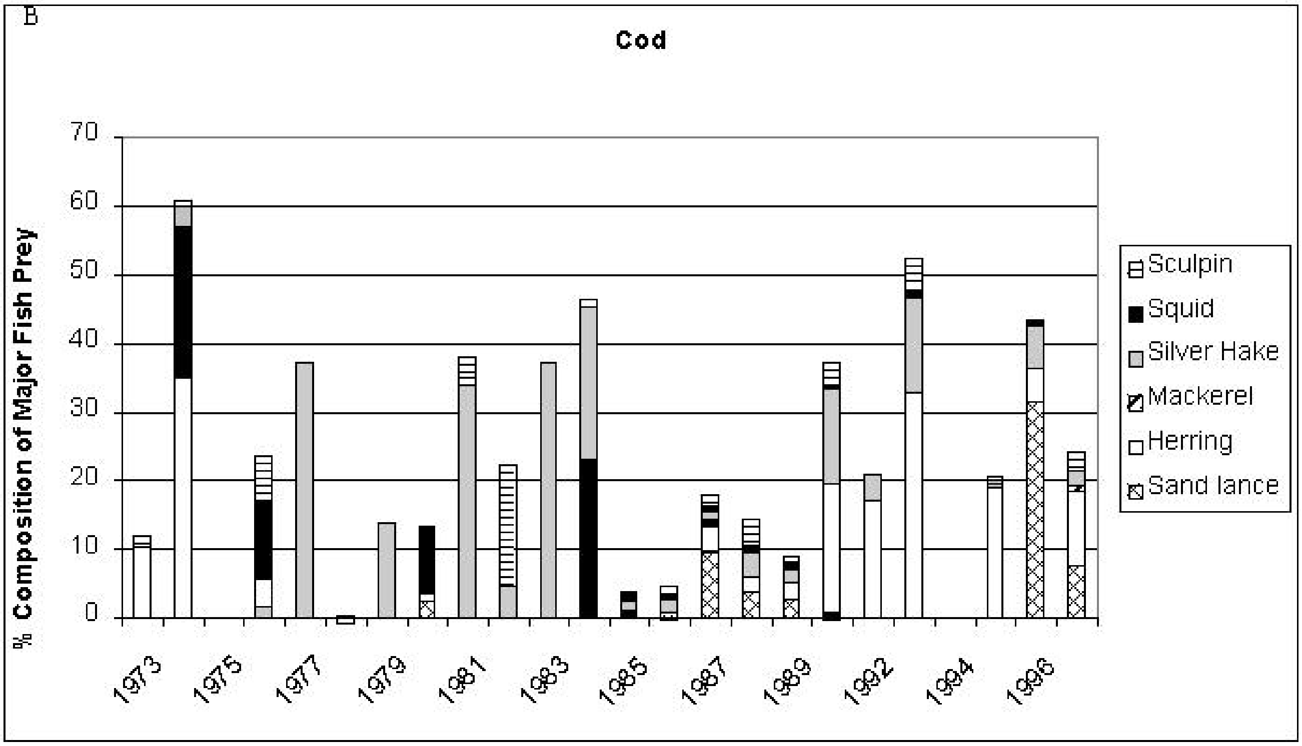


Figure B.47. ***Spiny dogfish % diet composition of major fish prey***

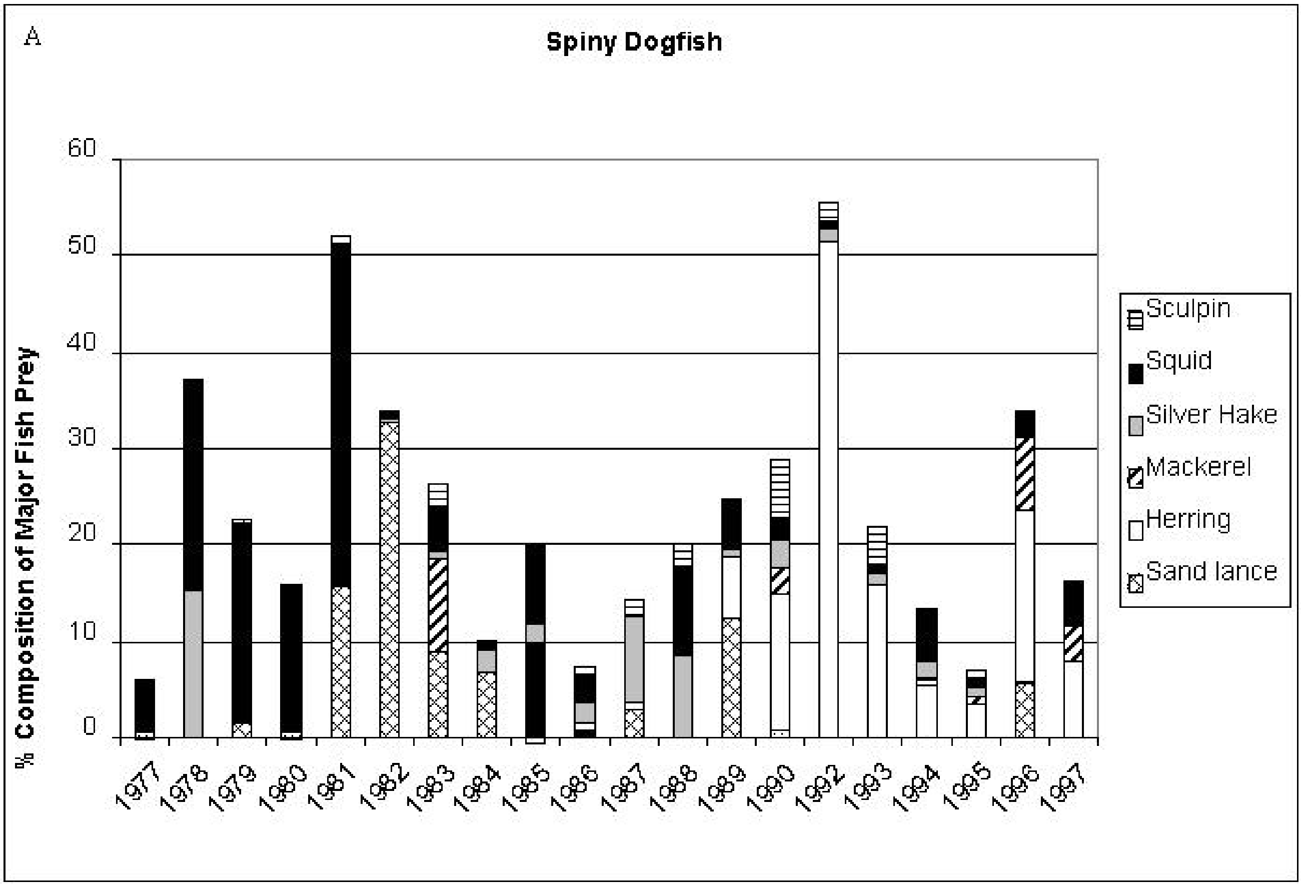


Figure B.48a. ***Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake***

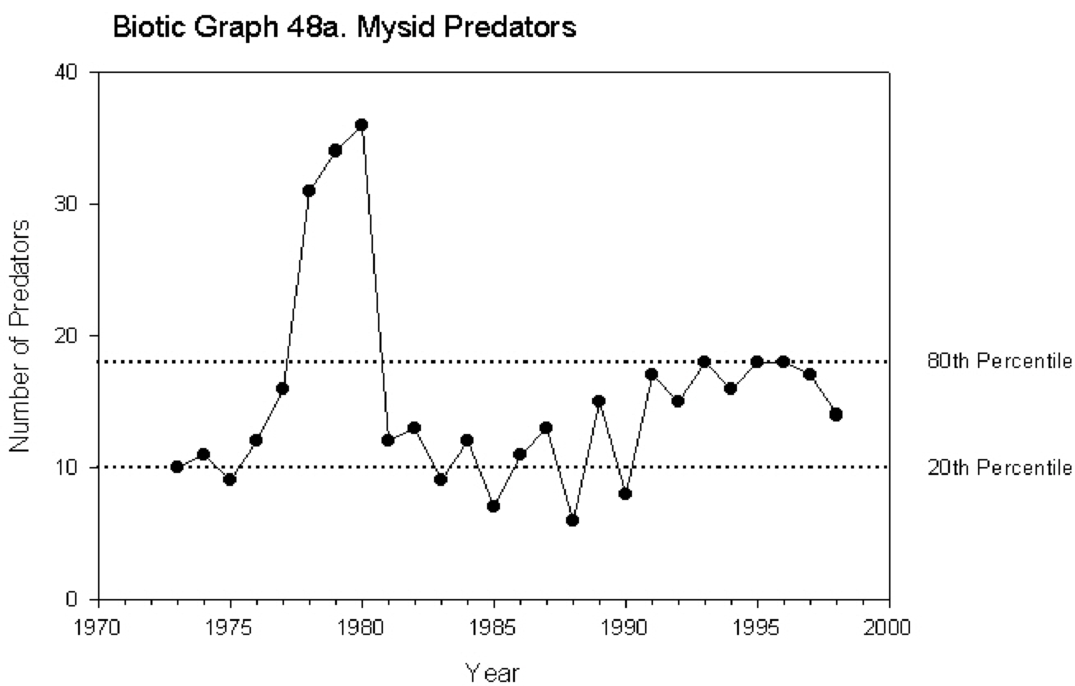


Figure B.48b. ***Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake***

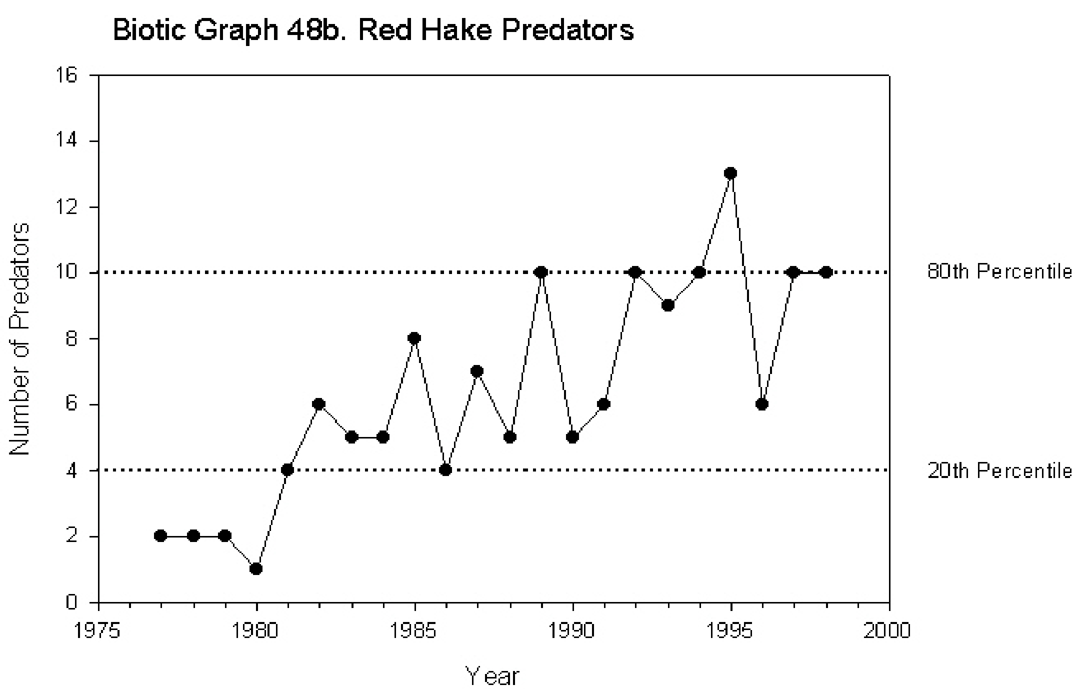


Figure B.48c. ***Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake***

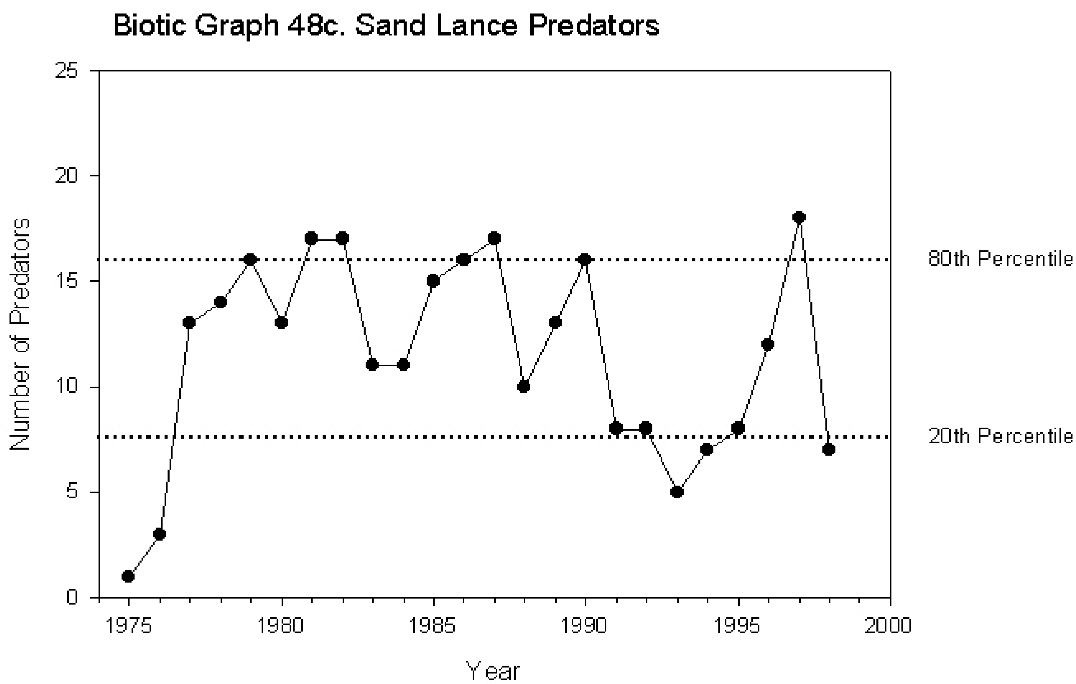


Figure B.48d. ***Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake***

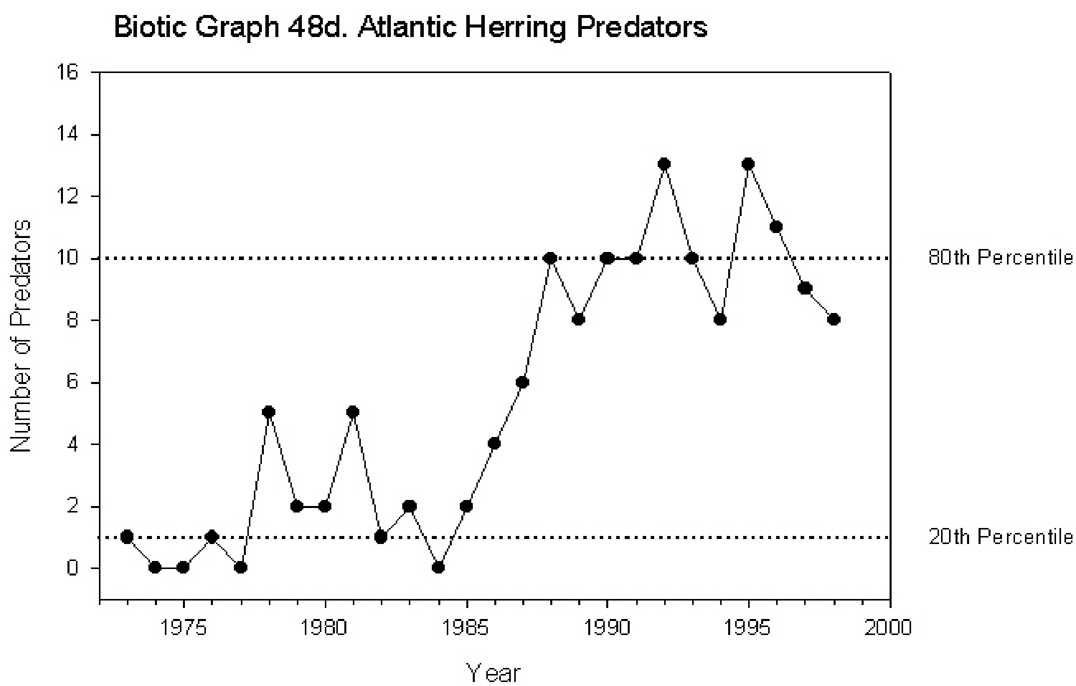


Figure B.48e. ***Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake***

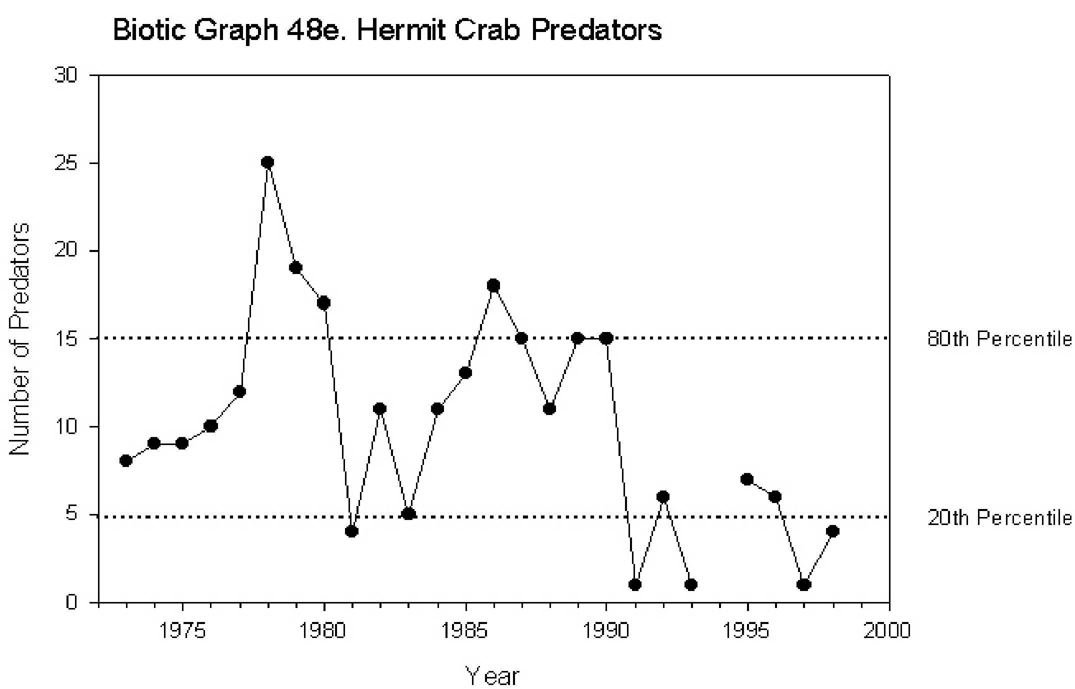


Figure B.48f. ***Number of predators for sand lance, herring, hermit crab, ophiuroids, mysids, and red hake***

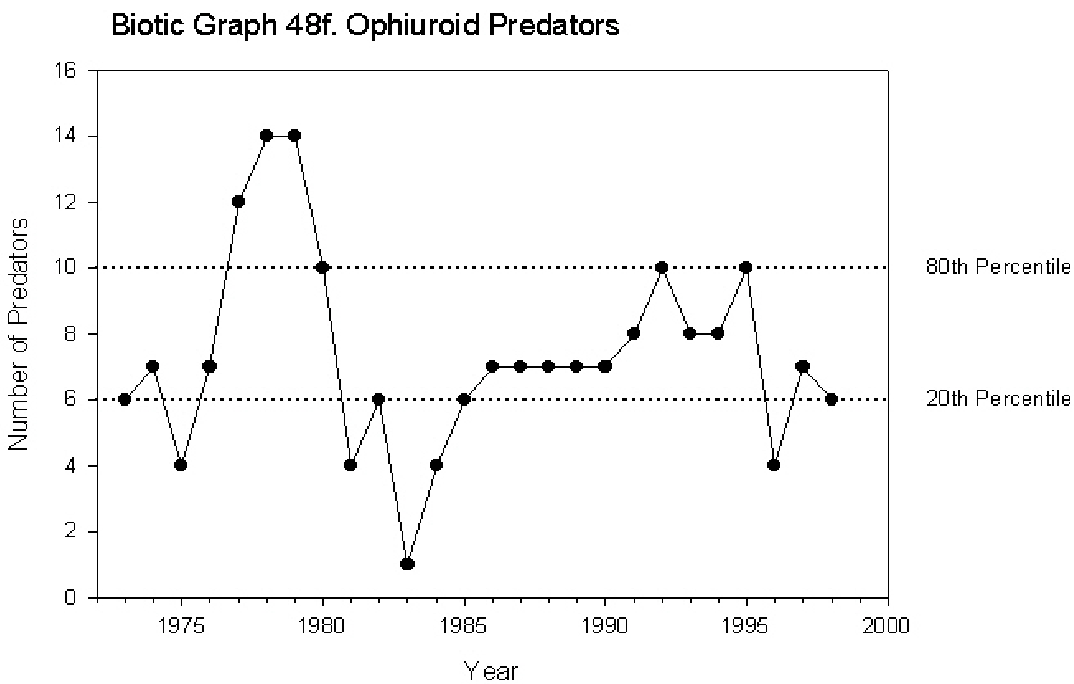


Figure B.49. ***Silver hake % cannibalism***

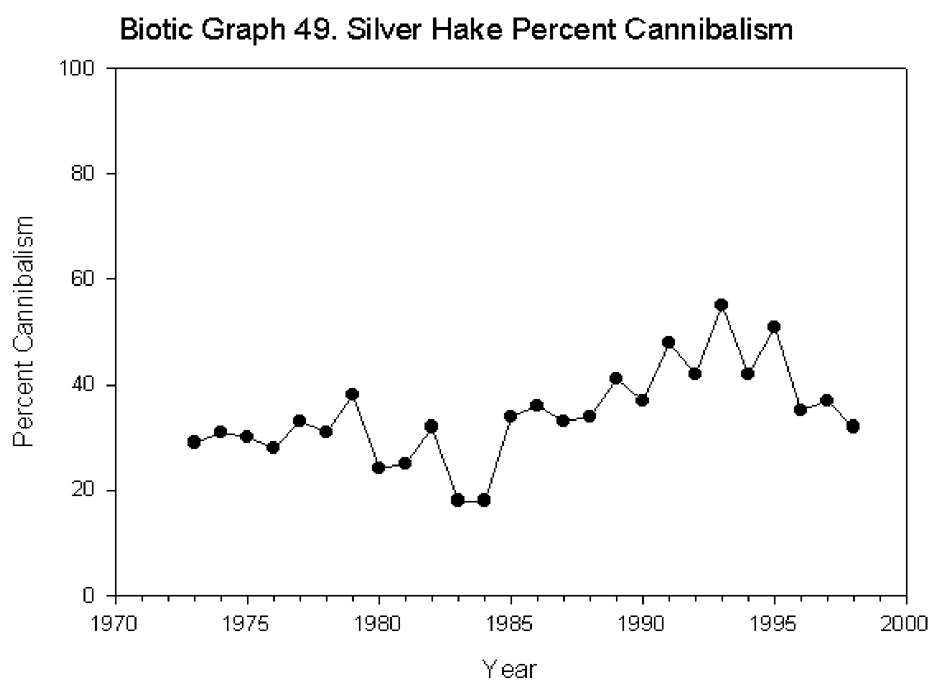


Figure B.50. ***Silver hake and red hake number of prey items***

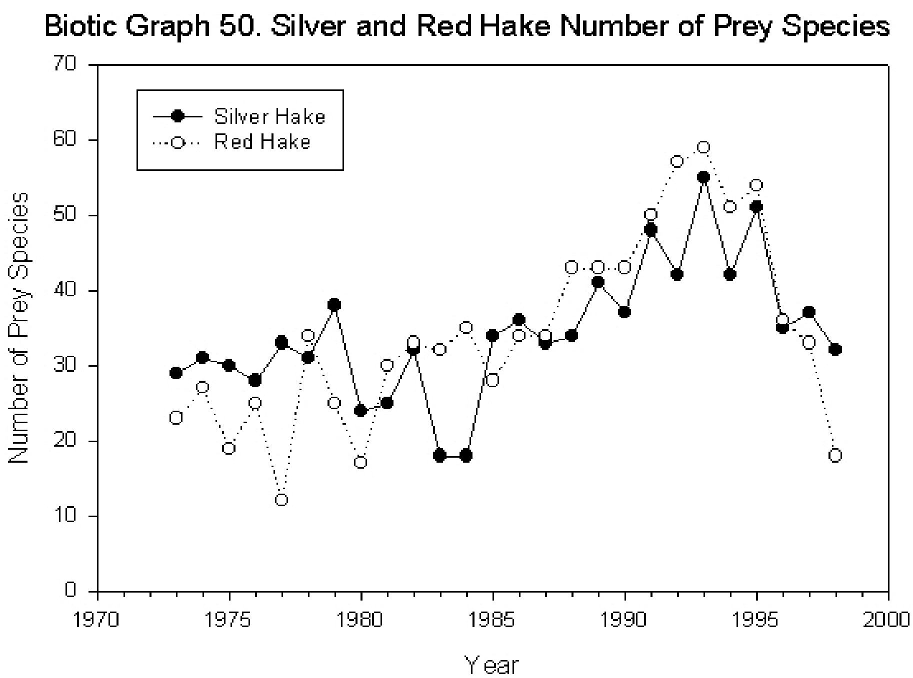


Figure B.51. ***Herring consumption to landings ratio***

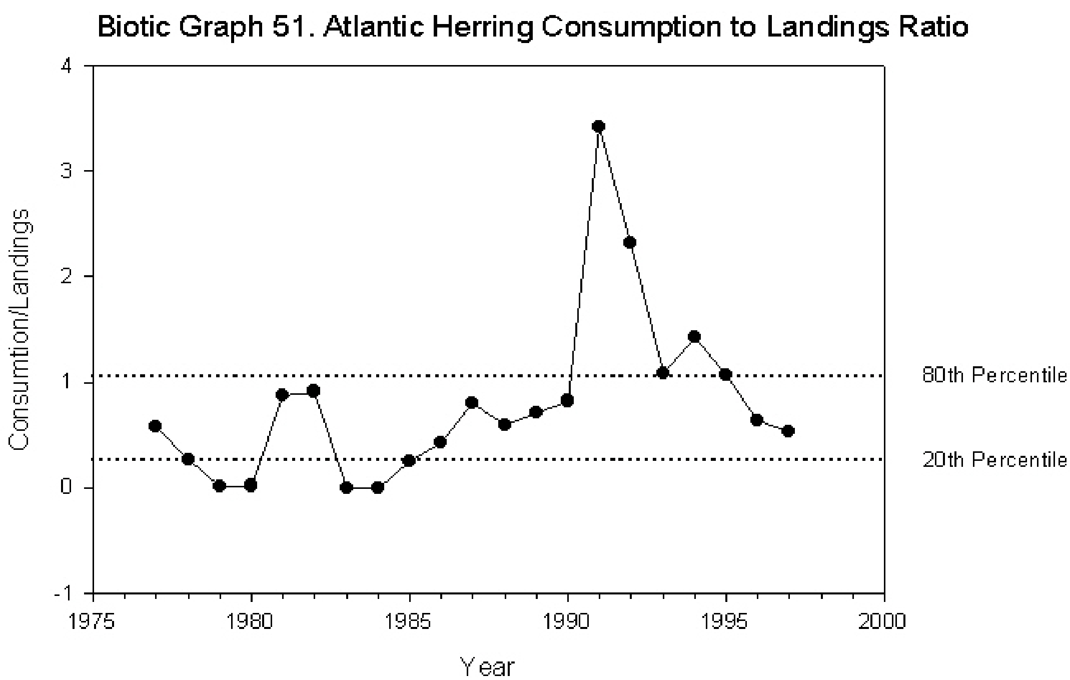


Figure B.52. ***Mackerel consumption to landings ratio***

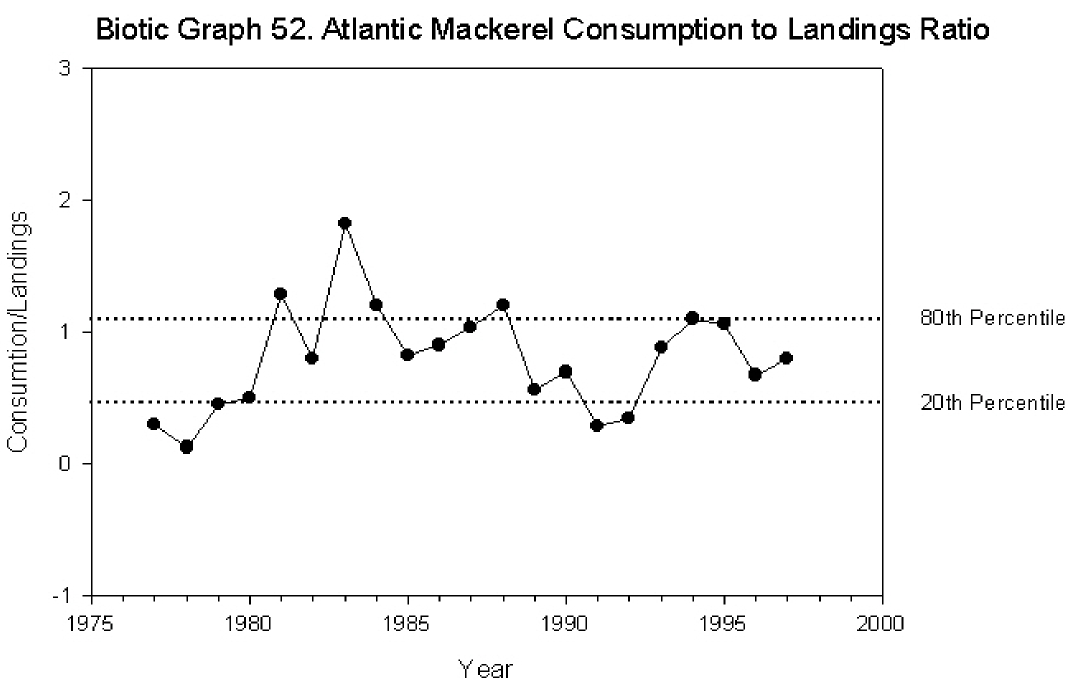
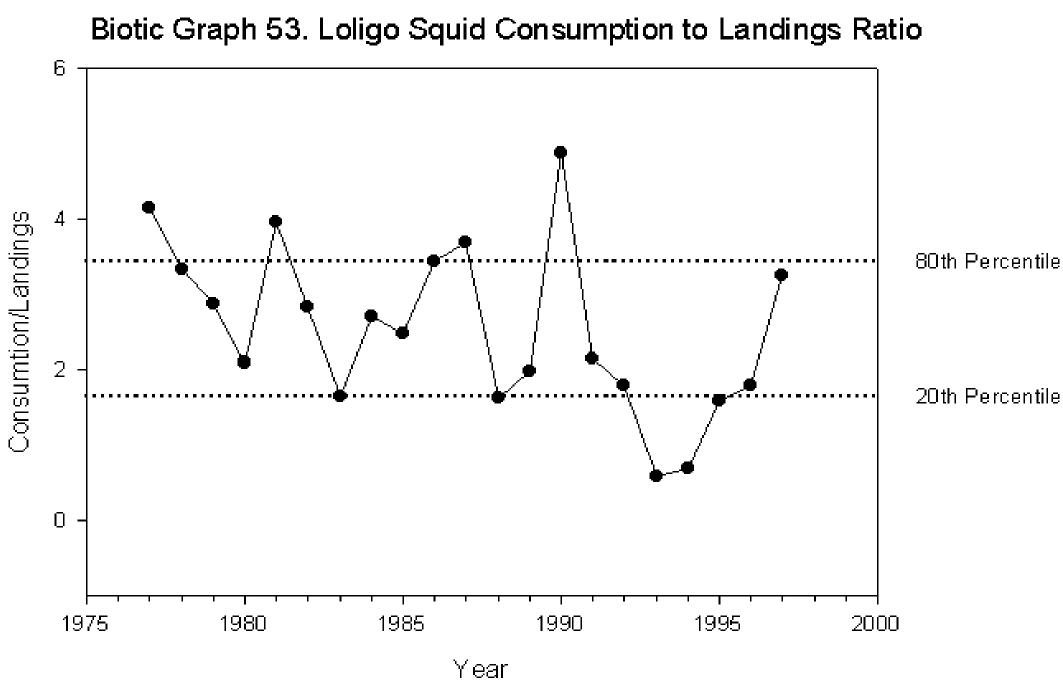


Figure B.53. **Loligo** ***consumption to landings ratio***



V. HUMAN METRICS

A. Recreational Fishing

We recognize that recreational fishing is an important part of this ecosystem. Although there is data available, no one from the group provided data for this report. Certainly this is an important issue to consider for some species, and merits further examination in the future.

B. Fishing Communities

What are the relevant communities of fishermen, what is the relation of communities at sea to communities on land, what are the social relations embodied in particular regional fishing practices? Are there appropriate indices of communities, people, and cultures that can provide insight into how this ecosystem functions and how the products and services and of this ecosystem are used beyond economics? Are there indices for other ecosystem goods and services?

Additionally, what about “anecdotal” or cultural environmental knowledge; e.g., do fishermen’s notions of space and environment coincide with scientific ones? If not, what are the implications for management structures? What environmental knowledge can/would fishermen contribute? What informal rules for resource access and use would or do fishermen or groups of fishermen regularly employ?

C. Commercial Fisheries

1. New England Otter Trawl Landings

Time: 1964-2000

Spatial: Shelf wide

Contributed by: Edwards

Figure H.1

Methodology and Data Source

These data are from the weighout database reported by dealers to NMFS. Annual landings by species (live weight) were combined according to the species managed by individual fishery management plans. Data are restricted to U.S. bottom trawl vessels that landed in Maine, New Hampshire, Massachusetts, or Rhode Island.

Key Points and Major Observations

New England otter trawl landings declined by two-thirds between 1964 and 2000. U.S. annual landings were higher before the Magnuson-Stevens Fisheries Conservation and Management Act was implemented in 1977 (MSFCMA). Landings peaked during the early 1980s after the MFCMA, but the overall trend has been downwards since that time. The traditional targets of otter trawl fishermen - i.e., Atlantic cod, haddock, yellowtail flounder - have declined in absolute and relative importance from about 240 million pounds or 44 percent of total trawl landings in 1964 to 36 million pounds or 20 percent. Other species managed by the New England Council's Multispecies Groundfish Plan have likewise declined in amount and importance. Otter trawlers now also significantly target monkfish and skates.

2. New England Otter Trawl Revenues

Time: 1964-2000

Spatial: Shelf wide

Contributed by: Edwards

Figure H.2

Methodology and Data Source

These data are from the weighout database reported by dealers to NMFS. Annual dockside revenues by species were combined according to the species managed by individual fishery management plans. Data are restricted to U.S. bottom trawl vessels that landed in Maine, New Hampshire, Massachusetts, or Rhode Island. Revenues were adjusted to 2000-dollars using the GDP implicit price deflator.

Key Points and Major Observations

Revenues were flat, averaging $150 million, until the New England fleet expanded following the MSFCMA. Revenues peaked during the early1980s at over $240 million and then declined to less than pre-MSFCMA levels since about 1995, averaging $130 million. The absolute and relative importance of the traditional target species declined from over $100 million and 60 percent during the mid-1960s to $24 million and less than 20 percent during the mid 1990s. Revenues from cod, haddock, and yellowtail flounder have since increased moderately. Despite a decline in landings, revenues have been supported by increases in consumer demand (population of seafood consumers and their income) which in turn increases dockside prices.

3. Total Number of Otter Trawl Vessels

Time: 1964-2000

Spatial: Shelf wide

Contributed by: Edwards

Figure H.3

Methodology and Data Source

These data are from the weighout database reported by dealers to NMFS. Number of U.S. otter trawl vessels with landings reported in Maine, New Hampshire, Massachusetts, or Rhode Island. Vessels are binned by tonnage class (5-50 gross registered tons in ton class 2, 51-150 grt in TC3, >150 in TC4)

Key Points and Major Observations

The total number of otter trawl vessels increased gradually up to 1977, particularly in TC3 and TC4. Vessel numbers increased quickly after the MSFCMA into the early 1980s from about 600 to 1000. There were increases in each vessel class. The total number of active otter trawl vessels has vacillated around 750 during the 1990s.

4. Total Income of NE Otter Trawl Fisherman (Profit)

Time: 1964-2000

Spatial: Shelf wide

Contributed by: Edwards

Figure H.4

Methodology and Data Source

These data are from the weighout database reported by dealers to NMFS. and NMFS cost data. Annual dockside revenues by species were combined according to the species managed by individual fishery management plans. Data are restricted to U.S. bottom trawl vessels that landed in Maine, New Hampshire, Massachusetts, or Rhode Island. Revenues were adjusted to 2000-dollars using the GDP implicit price deflator. Costs (also adjusted to 2000-dollars) are sample estimates from CMER (Cooperative Marine Education and Research) survey projects by the University of Rhode Island. Costs are for trip (e.g., fuel), repair and maintenance, and fixed (except unknown loan and depreciation) expenses. See Lallemand et al. (1998, 1999) for further details.

Key Points and Major Observations

Results should be considered rough approximations due to incomplete nature of cost data.

Total income vacillated around $80 million before the MSFCMA. Income peaked during the late1970s/early1980s and then trended downwards until 1996. Income has improved since 1996, but at less than $60 million it remains substantially below the pre-MSFCMA average. Income of crew averaged 40-50 percent of total income. Recent income is depressed relative to revenues because of the costs of excess harvest capacity.

5. Adjusted Average Income of NE Otter Trawl Fisherman

Time: 1964-2000

Spatial: Shelf wide

Contributed by: Edwards

Figure H.5

Methodology and Data Source

These data are from the weighout database reported by dealers to NMFS. and NMFS cost data. Annual dockside revenues by species were combined according to the species managed by individual fishery management plans. Data are restricted to U.S. bottom trawl vessels that landed in Maine, New Hampshire, Massachusetts, or Rhode Island. Revenues were adjusted to 2000-dollars using the GDP implicit price deflator. Costs (also adjusted to 2000-dollars) and crew size are sample estimates from CMER (Cooperative Marine Education and Research) survey projects by the University of Rhode Island. Costs are for trip (e.g., fuel), repair and maintenance, and fixed (except unknown loan and depreciation) expenses. Income was averaged over the number of vessels and approximate number of crew (2 crew in TC2, 4 in TC3, 5 in TC4). See Lallemand et al. (1998, 1999) for further details.

Key Points and Major Observations

Results should be considered rough approximations due to incomplete nature of cost and crew data. Average income per vessel and crew fluctuated considerably prior to the MSFCMA without trend. Average income trended downward since the late 1970s to lows of $25,000 per vessel and $8,000 per crew in 1996. Average income for vessel owners and crew has improved since 1996 but still remains below the pre-MSFCMA averages of about $80,000 and $20,000, respectively.

6. Standardized fishing effort on Georges Bank

Time: 1960-1987

Spatial: Georges Bank

Contributed by: Brodziak

Figure H.6

Methodology and Data Source

The multispecies and multifleet catch and effort data are reported to NAFO, standardized to account for differences in effective fishing effort using information on vessel size, gear, and country of origin using a general linear modeling approach. See Mayo et al. (1992) and Brodziak and Link (2002) for further details.

Key Points and Major Observations

Fishing effort was very high during the mid 1960s to mid 1970s when foreign distant water fleets were (over)harvesting fish on Georges Bank. Fishing effort declined by about 2/3 after passage of the Magnuson Stevens Fishery Conservation Act of 1976. This act extended the USAs Exclusive Economic Zone (EEZ) to include Georges Bank. Domestic fishing effort increased from 1977-1987, although this increase was moderate compared to the increase in distant water fleet effort in the 1960s.

7. Standardized catch-per-unit effort (CPUE) for Georges Bank fisheries

Time: 1960-1987

Spatial: GB

Contributed by: Brodziak

Figure H.7

Methodology and Data Source

Multispecies and multifleet catch and effort data reported to NAFO were used to compute standardized CPUE based on differences in vessel size, gear, and country of origin using a general linear model estimation approach. See Mayo et al. (1992) and Brodziak and Link (In press) for further details.

Key Points and Major Observations

Standardized CPUE declined from the early 1960s to mid 1970s as fish stocks were depleted. There was a short-term increase in CPUE after passage of the Magnuson Act in the late 1970s followed by a sharp decline through the mid 1980s. Fishery CPUE is not expected to be proportional to aggregate fish stock biomass. Instead, CPUE is likely a nonlinear function of fish biomass. In this context, the observed declines in CPUE are expected to underestimate the actual declines in fish stock biomass on Georges Bank.

8. Fishery harvest rate in relation to spawning biomass for Georges Bank haddock

Time: Composite picture, 1931-1998

Spatial: Georges Bank

Contributed by: Brodziak

Figure H.8

Methodology and Data Source

Under the current management approach, a target and a threshold harvest rate have been determined for Georges Bank haddock. The target and threshold depend on the current spawning biomass. The graph shows the observed fishing mortality and spawning biomass from an assessment of the Georges Bank haddock stock in relation to the target and threshold harvest rate lines. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

Harvest rates on the Georges Bank haddock stock have generally exceeded target rates during 1931-98. Thus, management measures have generally not been effective to ensure that the harvest rate has been near its target for this stock. Spawning stock biomass of Georges Bank haddock has begun to increase as harvest rates have been reduced in the 1990s. The 1998 data point shows the status of the spawning biomass is still well below target spawning biomass.

9. Georges Bank cod, haddock and yellowtail flounder yields

Time: 1935 - 2000

Spatial: Georges Bank

Contributed by: Brodziak

Figure H.9

Methodology and Data Source

Time series of total fishery landings for Georges Bank cod, haddock, and yellowtail flounder stocks were gathered from historical databases. These figures do not include discarded catches. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

Yields were high during the 1930s-1950s, peaked in the 1960s, declined in the 1970s, peaked again in the early 1980s, and then declined. Georges Bank cod, haddock, and yellowtail yields have increased moderately in recent years after reaching record lows in the mid 1990s. Landings of the three primary groundfish stocks on Georges Bank have been below the estimated long-term potential yield (LTPY) for most of the observed time series. One causal factor leading to the lack of achievement of the long-term potential yield from these three primary stocks has been chronic overfishing, e.g., fishermen catching fish faster than the stocks can replenish themselves.

10. Fishing Activity, by state (North)

Time: 1999

Spatial: Shelf wide

Contributed by: Olson

Figure H.10

Methodology and Data Source

These data were derived from the 1999 logbook dataset. Latitude-longitude coordinates from converted loran observations were used to locate fishing activity by state in various regions of the shelf. Coordinates were truncated to two decimal points for visual display. Only New England and upper Mid-Atlantic are displayed.

Key Points and Major Observations

Fishing-activity is in terms of both a proxy for total days/location (total days absent, except fractions thereof for trips recording multiple locations) summed over all commercial trips and vessels (size of dots) and by state of landing (color of dots). Coastal areas are dominated by their respective states, but there is considerably more mixing in more distant waters. What then is the relation between "community" and "territory"? Are there different kinds of communities? Are there kinds of informal management regimes operant in some of these territories-of-use? Different places show different practices: why, what different kinds of social relations are enabled in these different ways of fishing, and with what different kinds of implications?

11. Fishing Activity, by state (South)

Time: 1999

Spatial: Shelf wide

Contributed by: Olson

Figure H.11

Methodology and Data Source

These data were derived from the 1999 logbook dataset. Latitude-longitude coordinates from converted loran observations were used to locate fishing activity by state in various regions of the shelf. Coordinates were truncated to two decimal points for visual display. Only Mid-Atlantic waters are displayed.

Key Points and Major Observations

Fishing-activity is in terms of both a proxy for total days/location (total days absent, except fractions thereof for trips recording multiple locations) summed over all commercial trips and vessels (size of dots) and by state of landing (color of dots). Coastal areas are dominated by their respective states, but there is considerably more mixing in more distant waters. What then is the relation between "community" and "territory"? Are there different kinds of communities? Are there kinds of informal management regimes operant in some of these territories-of-use? Different places show different practices: why, what different kinds of social relations are enabled in these different ways of fishing, and with what different kinds of implications?

12. Summer Flounder Catch

Time: 1999

Spatial: Shelf wide

Contributed by: Olson

Figure H.12

Methodology and Data Source

These data were derived from the 1999 logbook dataset. Latitude-longitude coordinates from converted loran observations were used to locate fishing activity by state in various regions of the shelf. Coordinates were truncated to two decimal points for visual display. Only Mid-Atlantic waters are displayed.

Key Points and Major Observations

Fishing-activity is in terms of both a proxy for total days/location (total days absent, except fractions thereof for trips recording multiple locations) summed over all commercial trips and vessels that caught at least 300 pounds fluke. The size of the pie chart was determined by size of the total fluke catch, the color of the pie chart slices was determined by state of landing, and the size of the slice was determined by that state's total days at that location. This is a single-species representation. How does the management system in place (here, quotas by state of landing) affect the spatiality of fishing–are the bands of activity on fishing grounds by state of landing more clear-cut than the previous figures? If so, to what extent is that attributable to the management, to the bio-ecosystemic properties of fluke, and to fishing practices of fluke fishermen (Who is targeting fluke and who are generalists? Questions of seasonality, "community" and "territory" emerge again.)

13. New England landed value, by county

Time: 1994-2000

Spatial: Shelf wide

Contributed by: Olson

Figure H.13

Methodology and Data Source

These data are from dealer weigh-out records, including all vessels landing in New England counties, 1994-2000. The landed value is summed across all species by county of landing, joined with census county maps.

Key Points and Major Observations

Coupled with next figure (H.14), these data seem to show an "uneven" spatiality to temporal changes in fishing. Although changes in the number of vessels were similar over all counties, changes in landed value were not. Are there changes in landing practices, changes in social/spatial relations, etc.? An answer would require additional ethnographic research, as well as knowledge of other regional differences in fishing practices (targeted species, if any; type of fleet; etc.).

14. New England number of permitted vessels, by county

Time: 1997-2001

Spatial: Shelf wide

Contributed by: Olson

Figure H.14

Methodology and Data Source

These data are from permit data, 1997-2001 (application years). Distinct vessel numbers were counted and summed by homeport county, for New England only.

Key Points and Major Observations

Coupled with previous figure (H.13), these data seem to show an “uneven” spatiality to temporal changes in fishing. Although changes in the number of vessels were similar over all counties, changes in landed value were not. Are there changes in landing practices, changes in social/spatial relations, etc.? An answer would require additional ethnographic research, as well as knowledge of other regional differences in fishing practices (targeted species, if any; type of fleet; etc.).

15. Average days absent

Time: 1999

Spatial: Shelf wide

Contributed by: Olson

Figure H.15

Methodology and Data Source

These data were derived from the 1999 logbook dataset. Latitude-longitude coordinates from converted loran observations were used to locate fishing activity by state in various regions of the shelf. Coordinates were truncated to two decimal points for visual display. New England and Mid-Atlantic areas are displayed. All trips were summed by truncated locations; crew size averaged over trips at that location (not vessels). Does not account for “popularity” of sites.

Key Points and Major Observations

This graphical summary provides another way of displaying qualitative differences in use of fishing space, in terms of reading heterogeneity into fishing practices. Coastal waters are, unsurprisingly, dominated by day-trippers; trips in offshore waters vary in length. This isn't related solely or simply to biomass. Day-boat fishing is not practiced simply because the fish are close by and may as well be caught first, but because fishing as a day-boat is a social practice that is valued because of the other sorts of relations it enables (e.g. family, community on land etc.). If so, and especially in an "ecosystem-based fishery management" context, the effect of qualitative factors on ecosystem processes should also be considered.

16. Groundfish Landings

Time: 1995-2000

Spatial: Shelf wide

Contributed by: Olson

Figures H.16 and H.17

Methodology and Data Source

These data were derived from the 1995-2000 logbook dataset. The quantity kept of groundfish was summed by statistical area. Groundfish included: Atlantic cod, winter flounder, witch flounder, yellowtail flounder, American plaice, haddock, white hake, redfish, pollock, red hake, ocean pout, silver hake, monkfish, cusk, and wolffish

Key Points and Major Observations

These data show the temporal *and* spatial distribution of groundfish catches. To what extent do these variations correspond to species abundances, and to what extent do they correspond with social practices (as in previous graphs)?

17. Pelagic Landings

Time: 1995-2000

Spatial: Shelf wide

Contributed by: Olson

Figures H.18 and H.19

Methodology and Data Source

These data were derived from the 1995-2000 logbook dataset. The quantity kept of pelagic species was summed by statistical area. Pelagics included: bluefish, butterfish, Atlantic herring, Atlantic mackerel, and menhaden.

Key Points and Major Observations

These data show the temporal *and* spatial distribution of groundfish catches. To what extent do these variations correspond to species abundances, and to what extent do they correspond with social practices (as in previous graphs)?

18. Bigeye Tuna Landings and Value

Time: 1993-1997

Spatial: Atlantic

Contributed by: Link

Figure H.20

Methodology and Data Source

These data were obtained from NMFS "Status of the Stocks" indicating the total value and biomass of tuna landed. See NMFS (1999) for further details.

Key Points and Major Observations

Although a short time series, there is a decline in recent years. This represents information from large, apex predators.

19. Atlantic Cod Landings and Value

Time: 1993-1997

Spatial: Atlantic

Contributed by: Link

Figure H.21

Methodology and Data Source

These data were obtained from NMFS "Status of the Stocks" indicating the total value and biomass of cod landed. See NMFS (1999) and NEFSC (1998) for further details.

Key Points and Major Observations

Although a short time series, there is a decline in recent years. This represents information from a culturally, ecologically, and economically important species in this ecosystem.

20. Swordfish Landings and Value

Time: 1993-1997

Spatial: Atlantic

Contributed by: Link

Figure H.22

Methodology and Data Source

These data were obtained from NMFS “Status of the Stocks” indicating the total value and biomass of tuna landed. See NMFS (1999) and NEFSC (1998) for further details.

Key Points and Major Observations

Although a short time series, there is a decline in recent years. This represents information from large, apex predators.

D. Fisheries Management (Governance)

1. Fraction of Georges Bank closed year-round to fishing

Time: 1977-2000

Spatial: Georges Bank

Contributed by: Brodziak

Figure H.23

Methodology and Data Source

Several large areas of Georges Bank were closed year-round to fishing in 1995 to help conserve and rebuild depleted groundfish stocks. Fishing vessels can transit through these areas but cannot fish there. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

Over 25% of Georges Bank was closed to fishing in the mid 1990s. Prior to these closures, some areas were closed on a seasonal basis.

2. Minimum mesh size regulations for trawl fishing nets

Time: 1977-2000

Spatial: Northeast USA shelf fisheries

Contributed by: Brodziak

Figure H.24

Methodology and Data Source

Minimum trawl mesh sizes for large-mesh otter trawl fisheries have been adjusted since 1977 to help to conserve groundfish under the New England Fishery Management Multispecies Fishery Management Plan. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

Minimum mesh sizes were increased in 1983 and 1994 to help conserve groundfish. Larger mesh sizes retain fewer small, unmarketable fish in the codend of the trawl net. Thus, a larger minimum mesh leads to less bycatch of juvenile fishes.

3. Days-at-sea restrictions for groundfish vessels

Time: 1977-2000

Spatial: Northeast USA groundfish fisheries

Contributed by: Brodziak

Figure H.25

Methodology and Data Source

The total number of days a fishing vessel can spend at sea were regulated in 1996 for the purpose of reducing fishing effort directed at depleted New England groundfish stocks. This effort regulation applies to New England groundfish fisheries. See Brodziak and Link (2002) for further details.

Key Points and Major Observations

Prior to 1996, there was no restriction on the number of days domestic fishing vessels could be fishing. Some large vessels received more than 120 days at sea based on their fishing history - the graph shows the default allocation that most vessels received.

E. Summary of Human Metrics

There has been a clear change in the effort, landings, and profit of the fishing fleet over the past four decades. Major events include a shift in targeted species, a decline in the poundage and value of landings, and an increase in the number of vessels after the late 1970s. This corresponds to the passage and implementation of the MSFCMA. Landings of two apex predators and Atlantic cod in more recent years show, although short term, a similar decline during the 1990s, perhaps due to changes in regulation of these species.

The patterns of spatial allocation of fishing effort and landings are logical given the logistic and cultural constraints in the region. Although these maps are relatively short time-series, historical data may be available to extend this analysis back for approximately 30 years. What is the role of other non-fishing sources of income in the decision-making process of whether to fish?

Regulations on the fisheries have become increasingly restrictive in recent years, with changes in closed areas, mesh size, and days at sea all much less lenient than in the 1960s and 1970s.

F. References

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Mayo, R., M. Fogarty, and F. Serchuk. 1992. Aggregate fish biomass and yield on Georges Bank, 1960-87. J. Northw. Atl. Fish. Sci. 14:59-78.

NEFSC 1998. Status of the Fishery Resources off the Northeastern United States. NOAA Technical Memorandum NMFS-NE-115.

NMFS. 1999. Fisheries of the United States, 1998. Current Fishery Statistics No. 9800.

Figure H.1. ***New England Otter Trawl Landings***

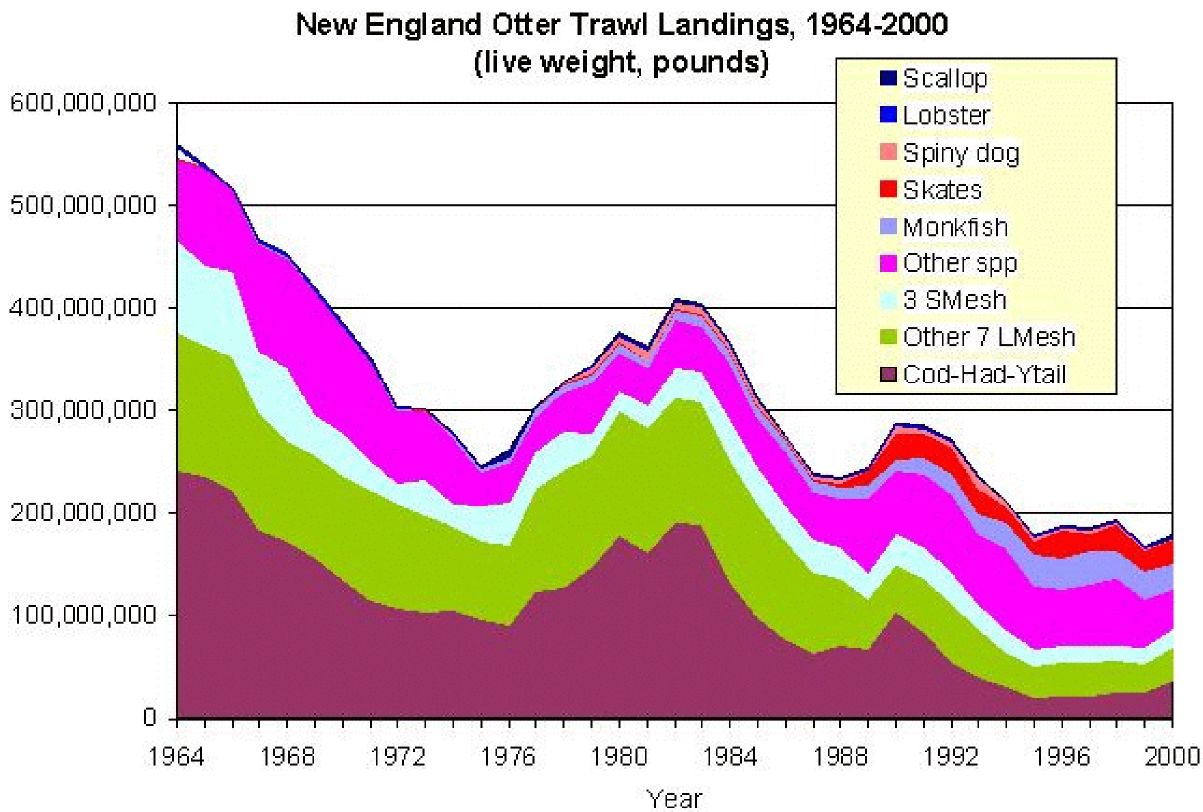


Figure H.2. ***New England Otter Trawl Revenues***

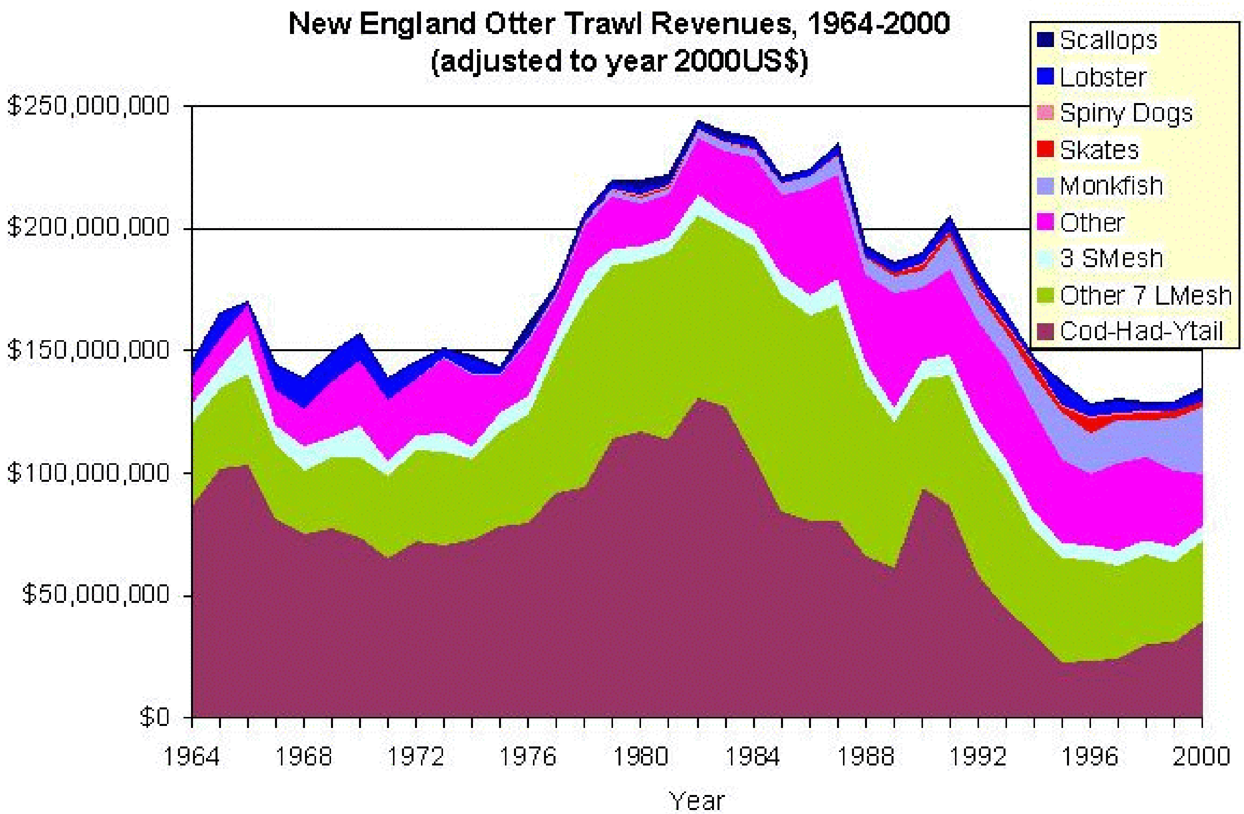


Figure H.3. ***Total Number of Otter Trawl Vessels***

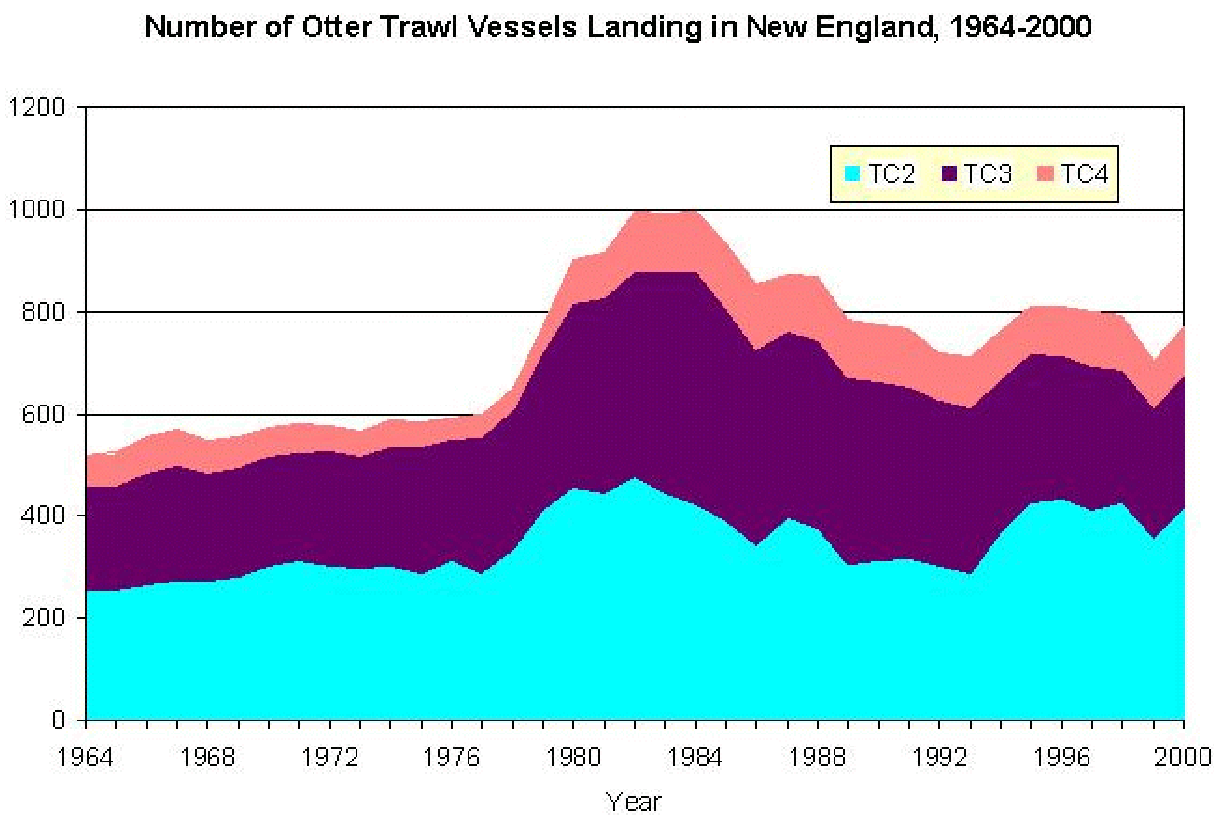


Figure H.4. ***Total Income of NE Otter Trawl Fisherman (Profit)***

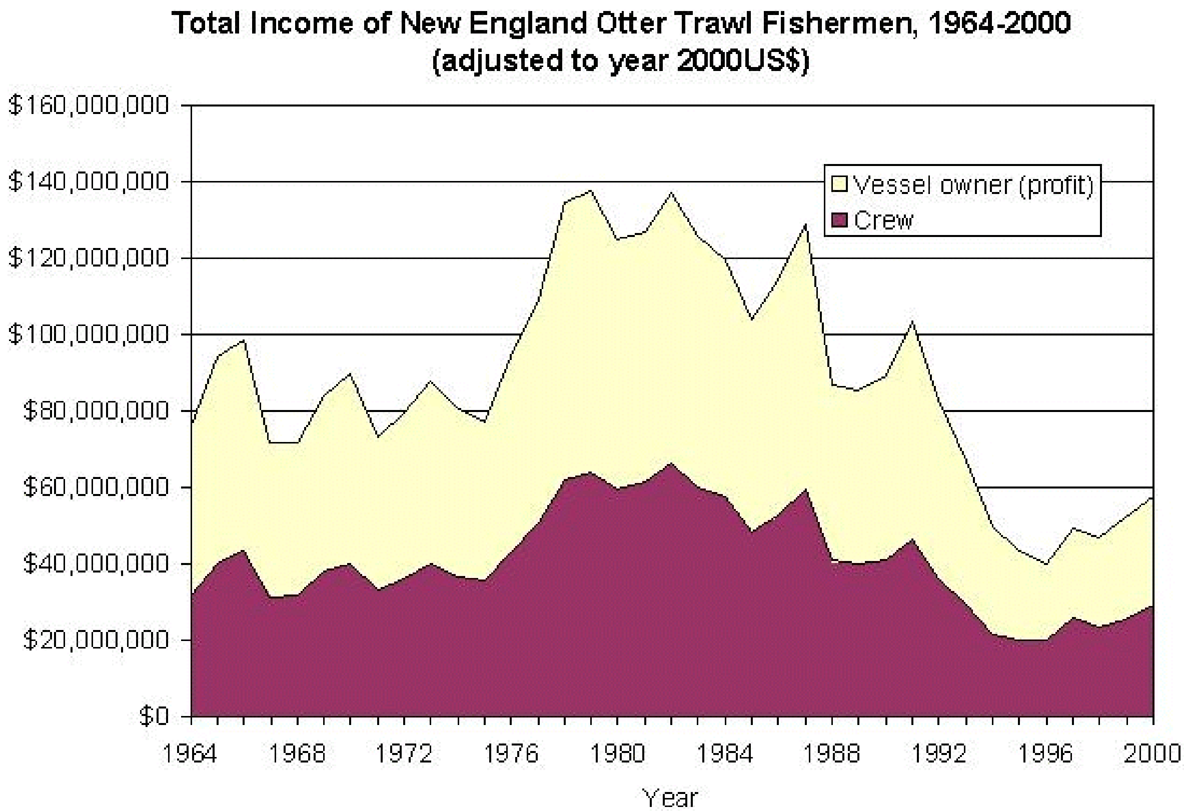


Figure H.5. ***Adjusted Average Income of NE Otter Trawl Fisherman***

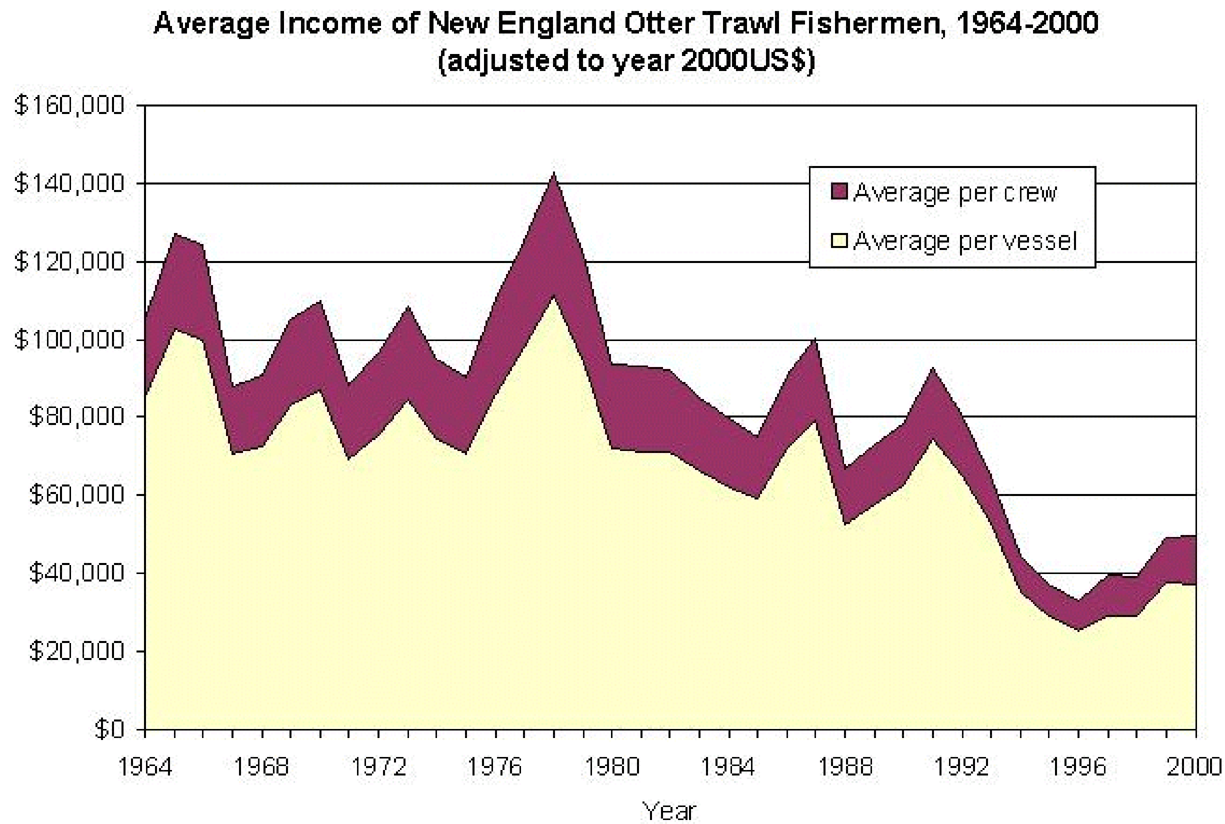


Figure H.6. ***Standardized fishing effort on Georges Bank***

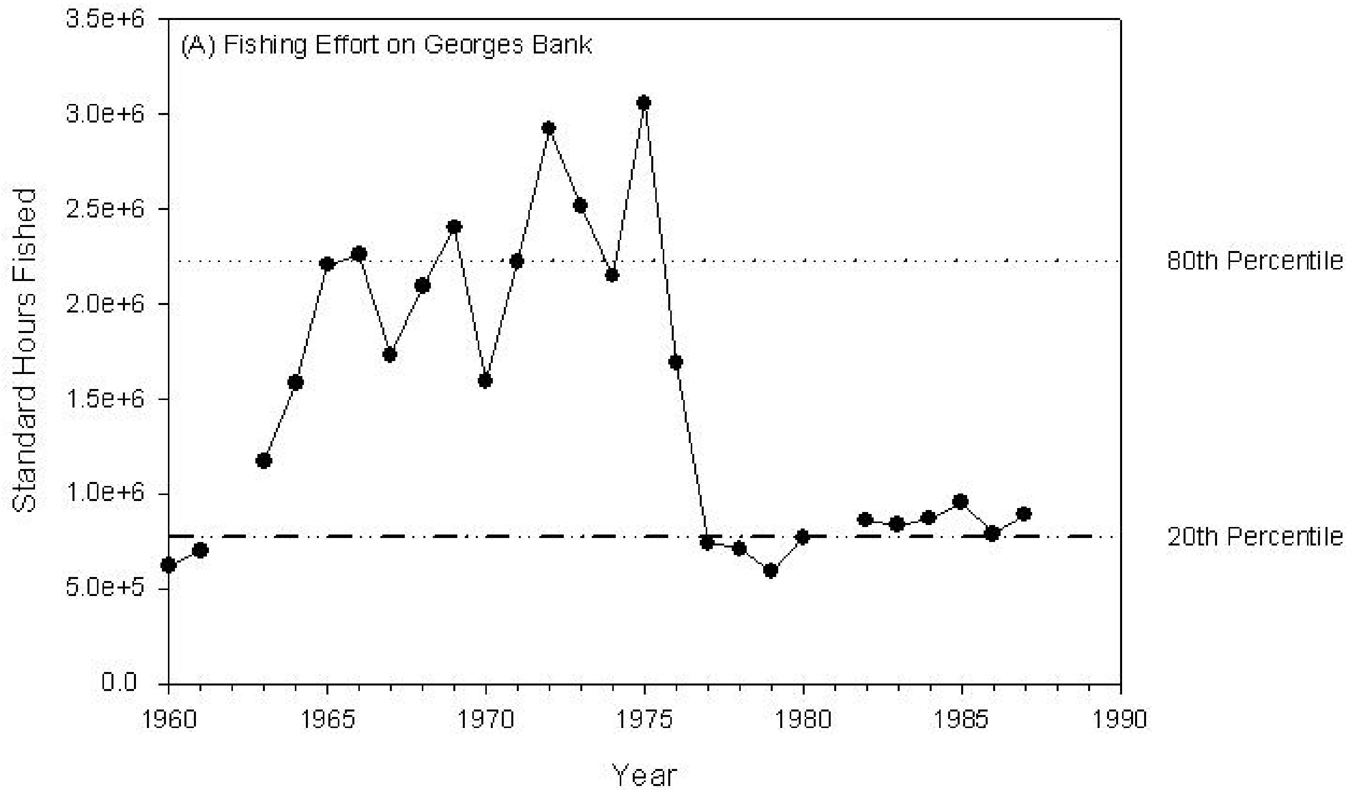


Figure H.7. ***Standardized catch-per-unit effort (CPUE) for Georges Bank fisheries***

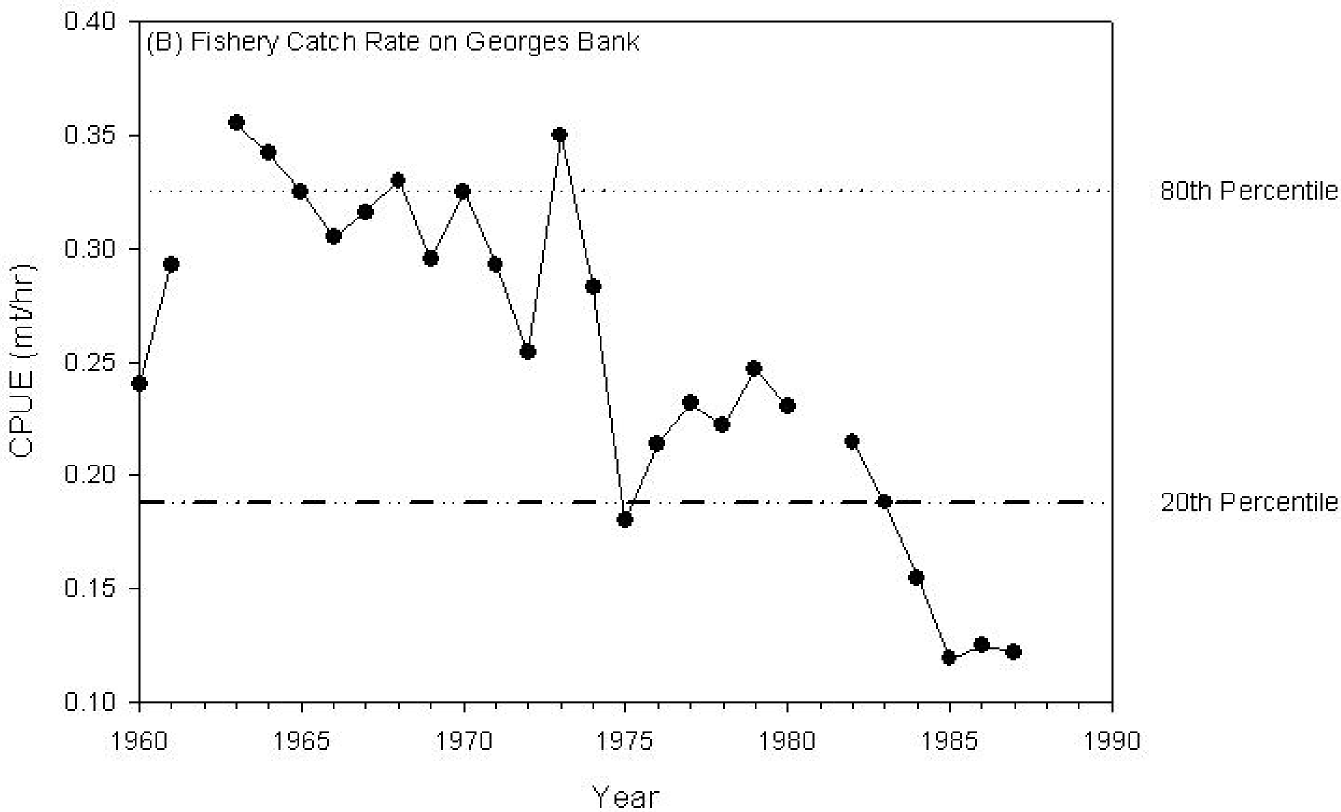


Figure H.8. ***Fishery harvest rate in relation to spawning biomass for Georges Bank haddock***

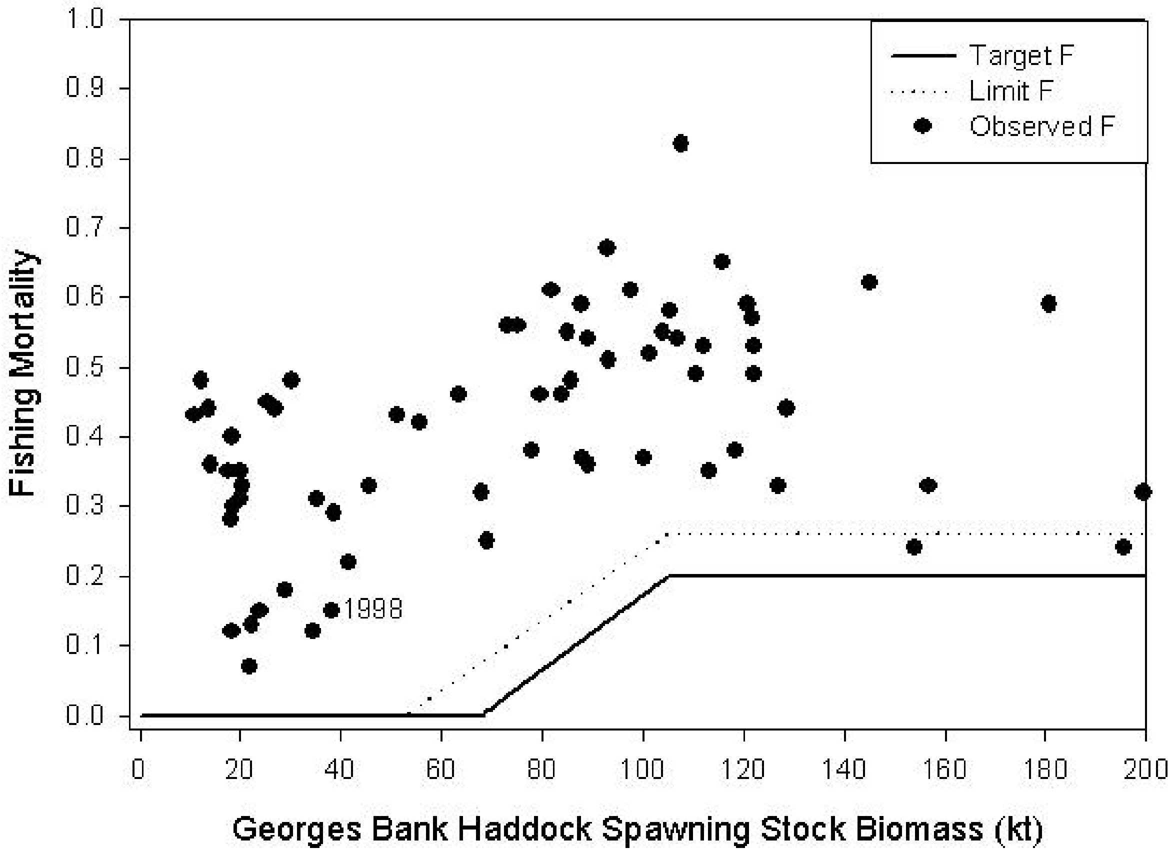


Figure H.9. ***Georges Bank cod, haddock and yellowtail flounder yields***

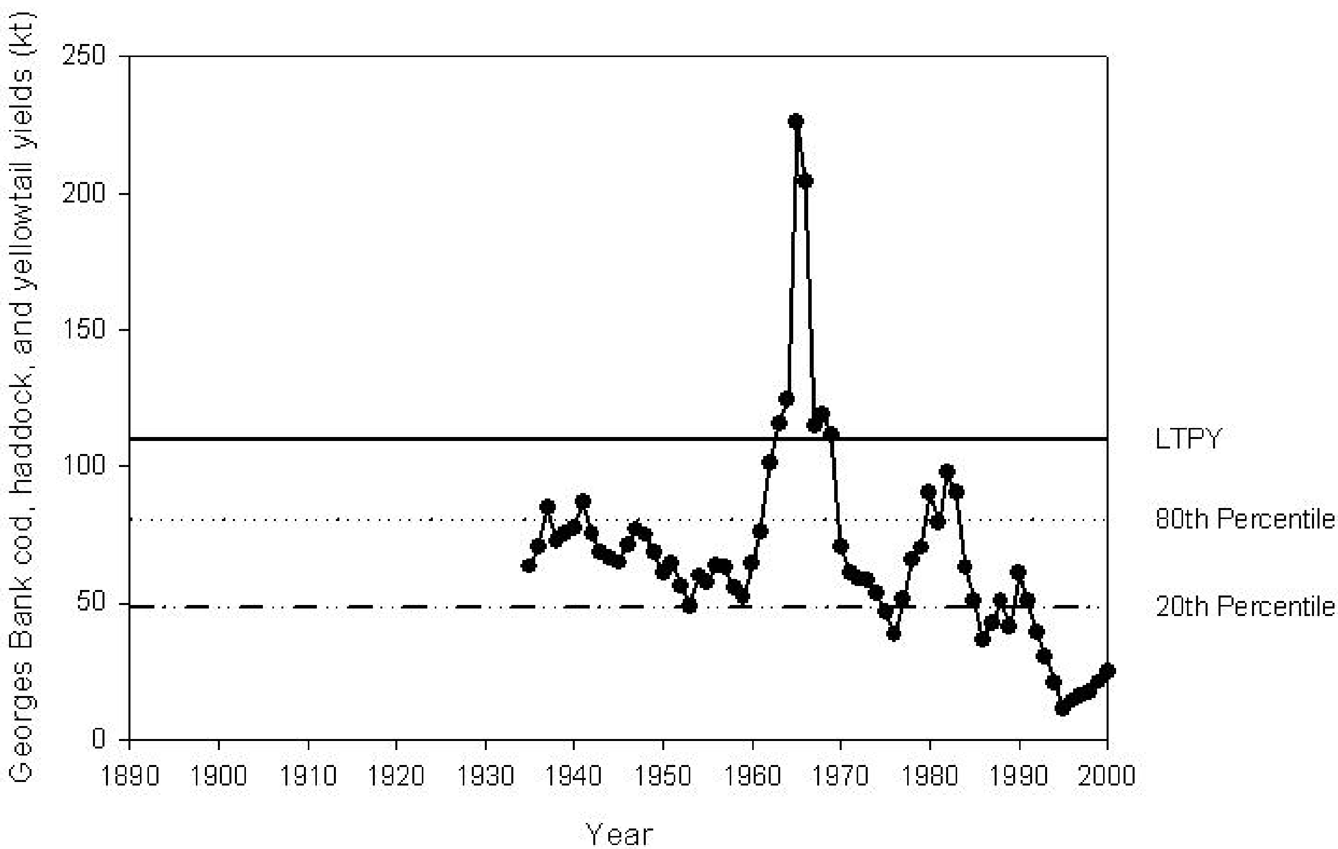
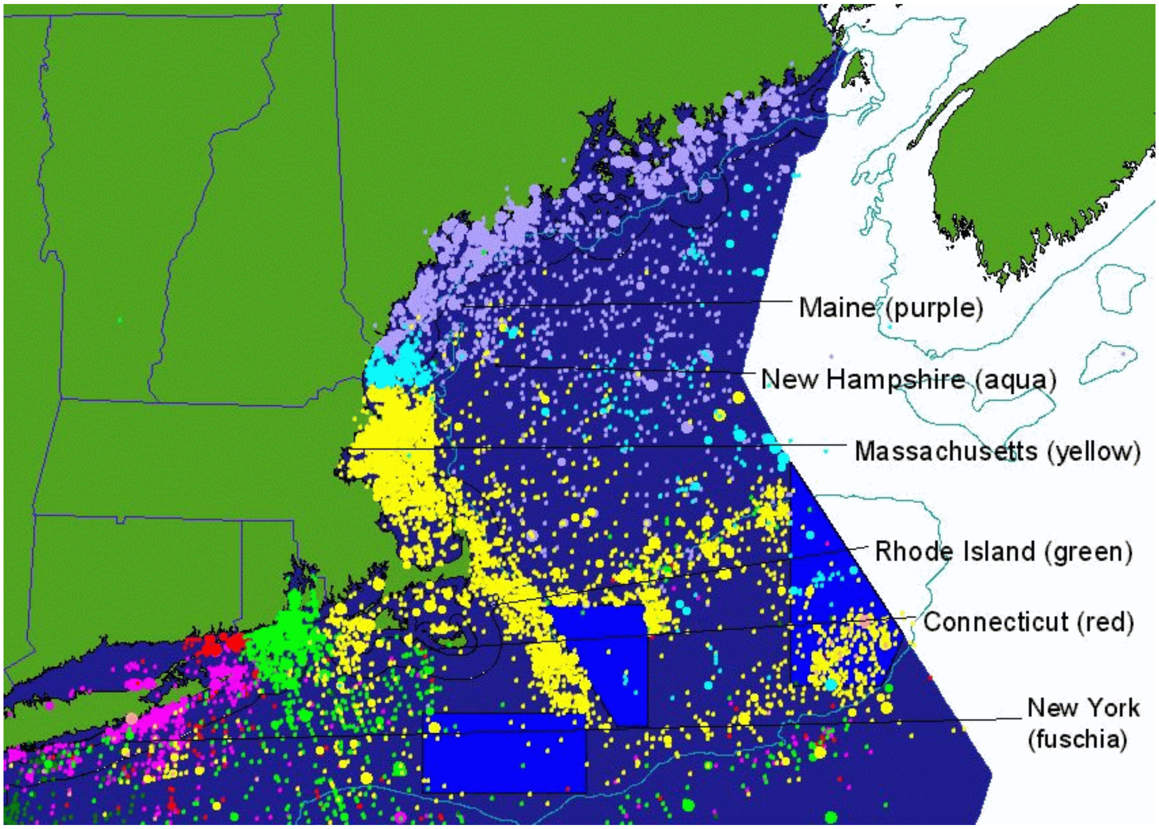
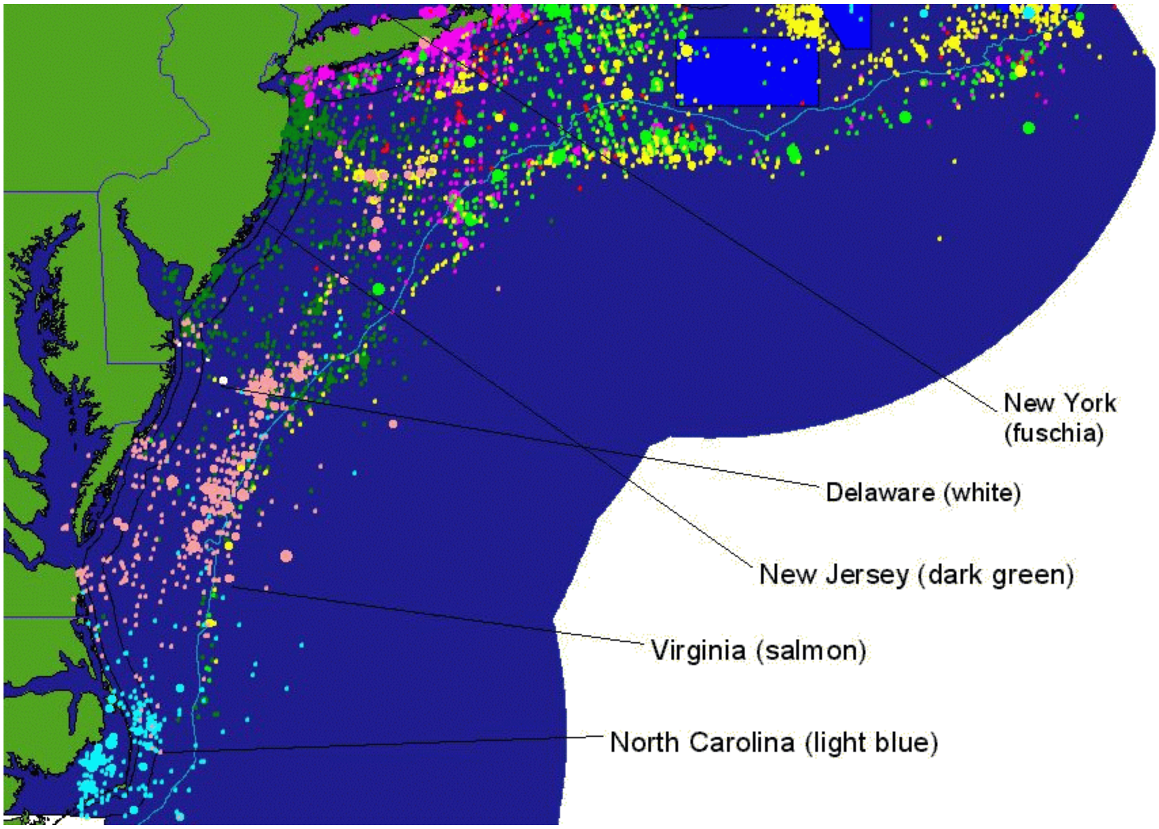


Figure H.10. ***Fishing Activity, by state (North)***



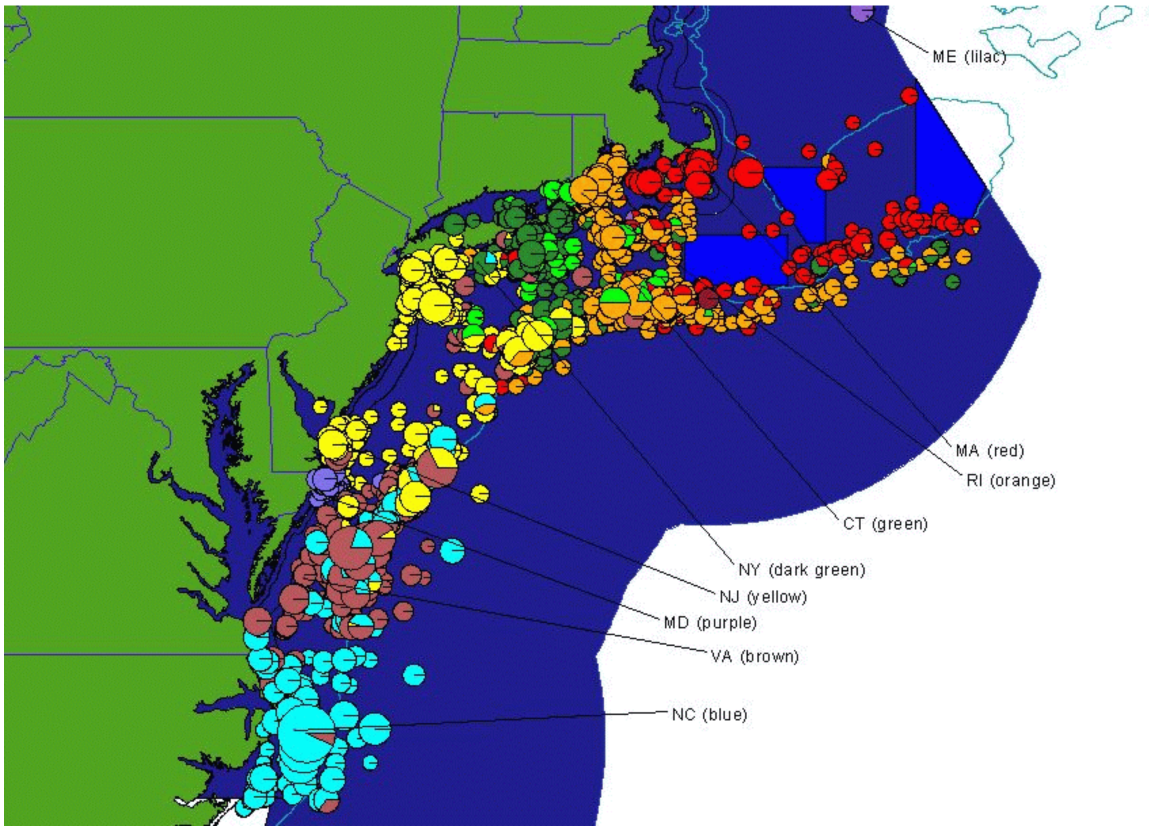
Fishing activity (total days absent) by state of landing, 1999. Source: 1999 logbook data, loran conversions.

Figure H.11. ***Fishing Activity, by state (South)***



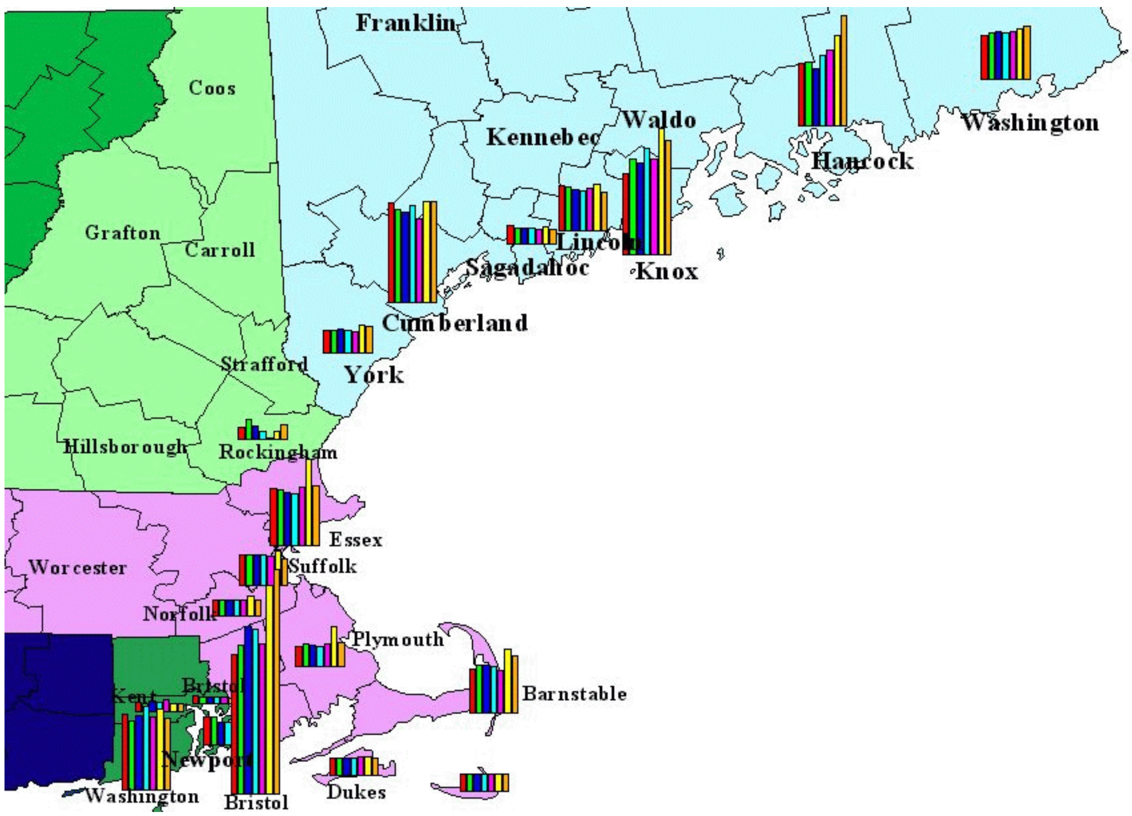
Fishing activity (total days absent) by state of landing, 1999. Source: 1999 logbook data, loran conversions.

Figure H.12. ***Summer Flounder Catch***



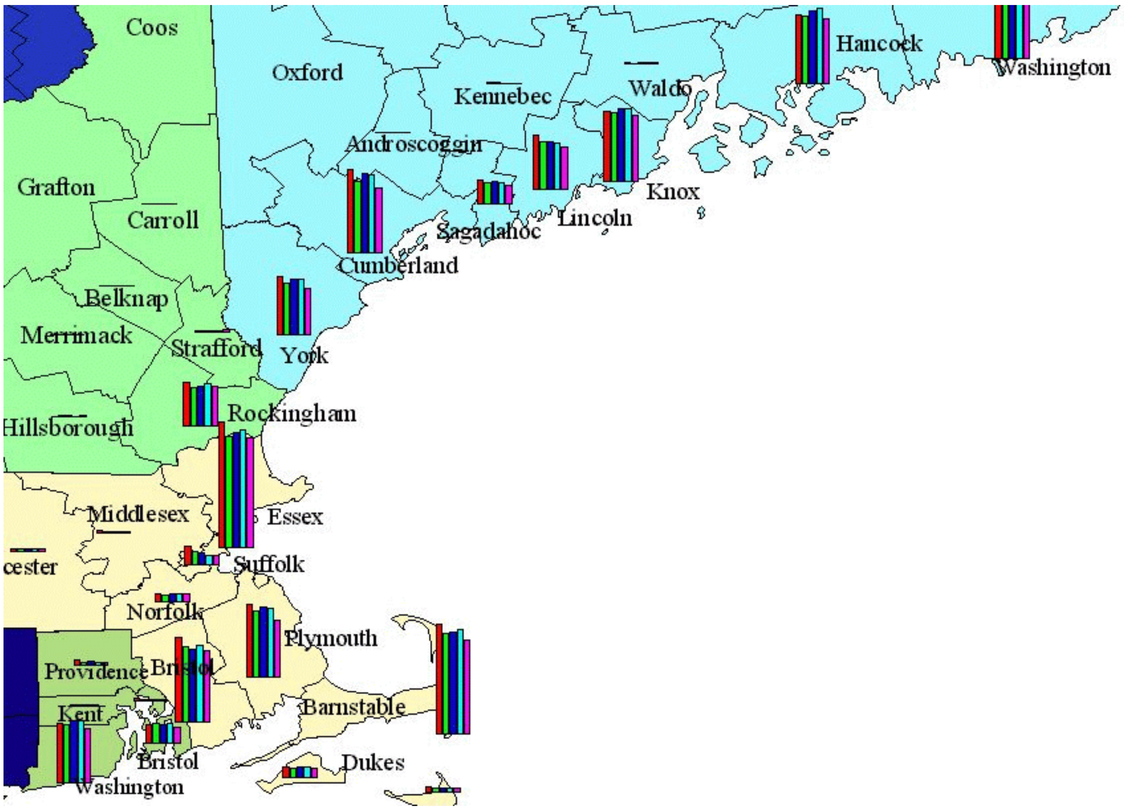
1999 Summer Flounder catch sites (greater than 300 pounds). Dots represent sites of fishing activity by state of landing (color of pie chart) and size of catch (size of pie chart). Source: 1999 vessel logbooks, loran conversions.

Figure H.13. ***New England landed value, by county***



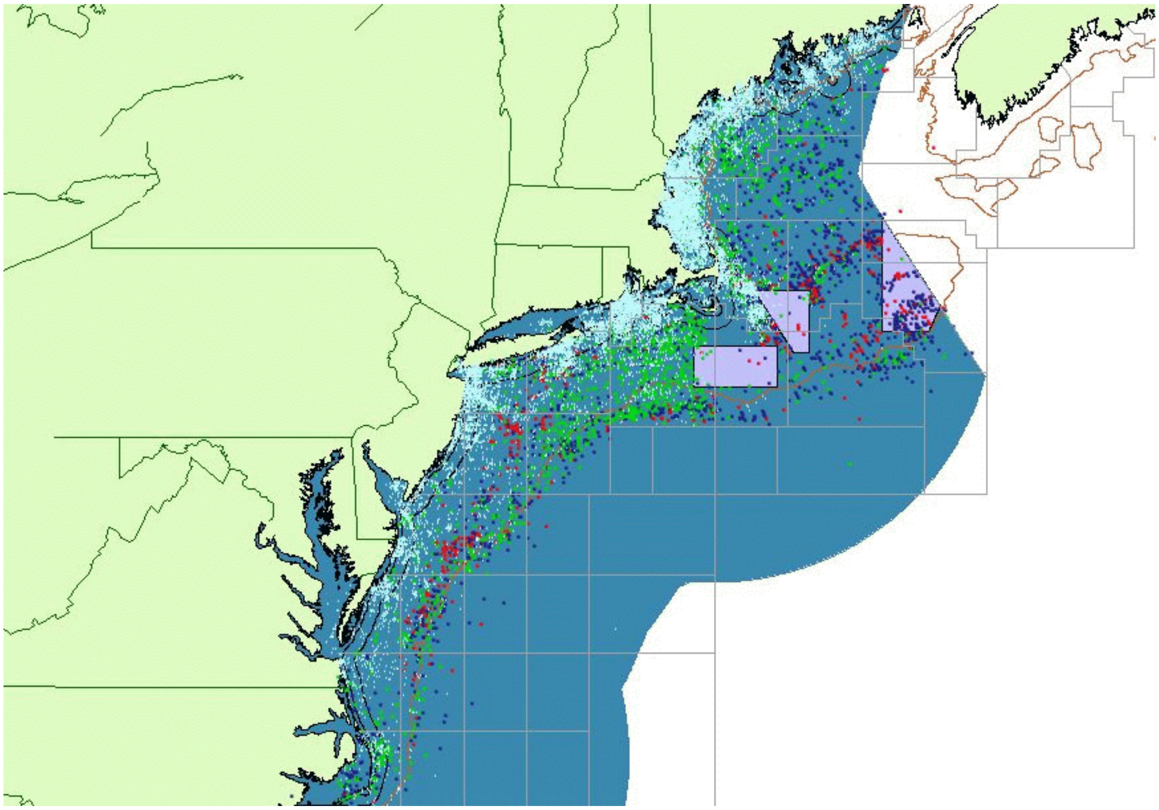
New England landed value by county, 1994-2000. Source: dealer weigh-out records.

Figure H.14. ***New England # permitted vessels, by county***



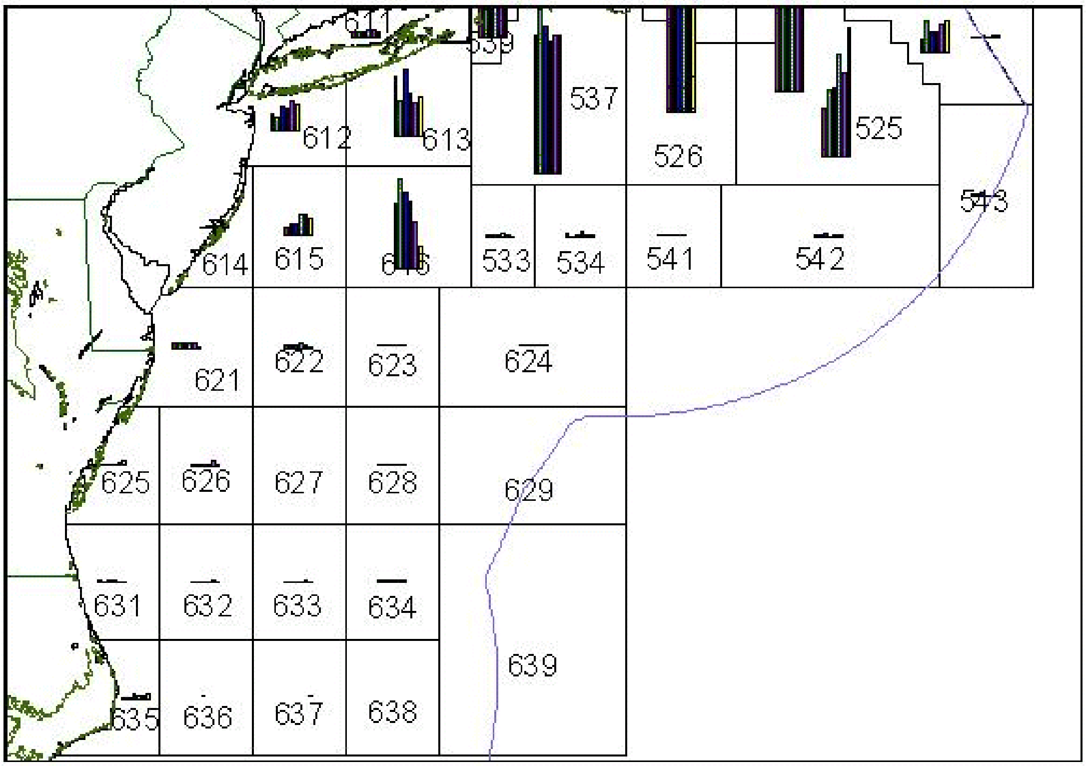
Number of federally permitted vessels by county, 1997-2001. Source: Northeast permit data.

Figure H.15. ***Average days absent***



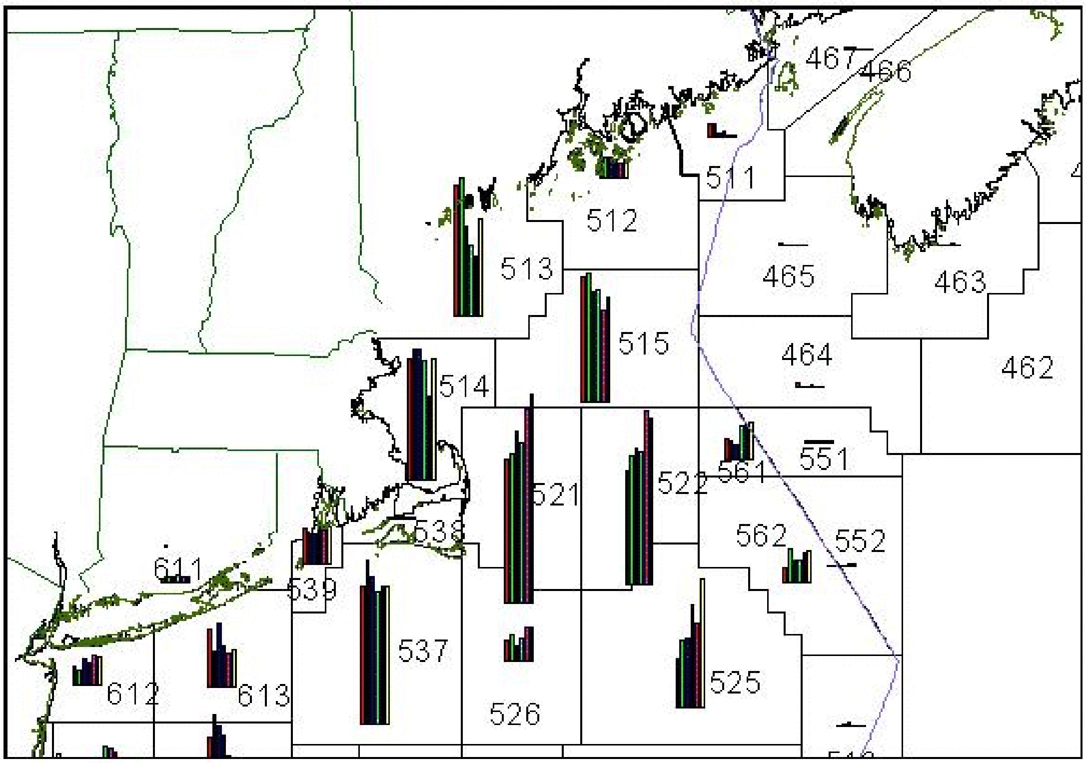
Average days absent per location. (Light blue = 1-2 days absent; green = 2.1-4 days absent; dark blue = 4.1-9 days absent; red = 9.1+ days absent). Source: 1999 logbook data, loran conversions.

Figure H.16. ***Groundfish Landings***



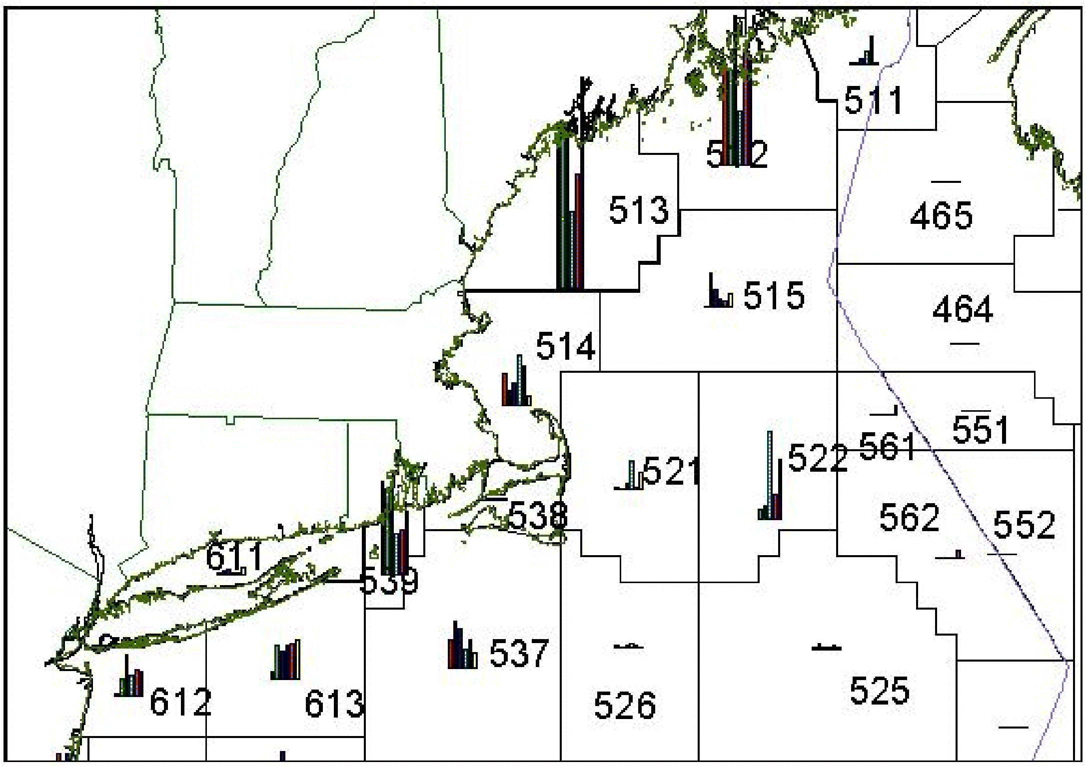
Groundfish landings in pounds, by statistical area (1995-2000). Source: logbook data.

Figure H.17. ***Groundfish Landings***



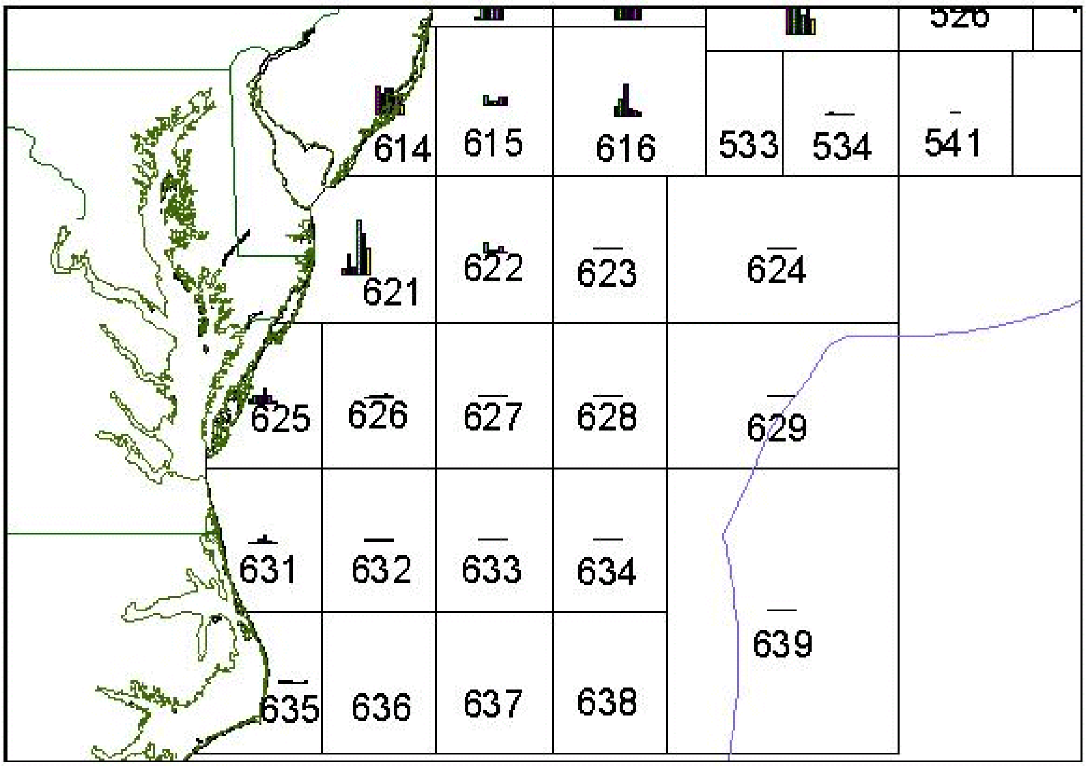
Groundfish landings in pounds, by statistical area (1995-2000). Source: logbook data.

Figure H.18. ***Pelagic Landings***



Landings of pelagic species in pounds, by statistical area (1995-2000). Source: logbook data.

Figure H.19. ***Pelagic Landings***



Landings of pelagic species in pounds, by statistical area (1995-2000). Source: logbook data.

Figure H.20. ***Bigeye Tuna Landings and Value***

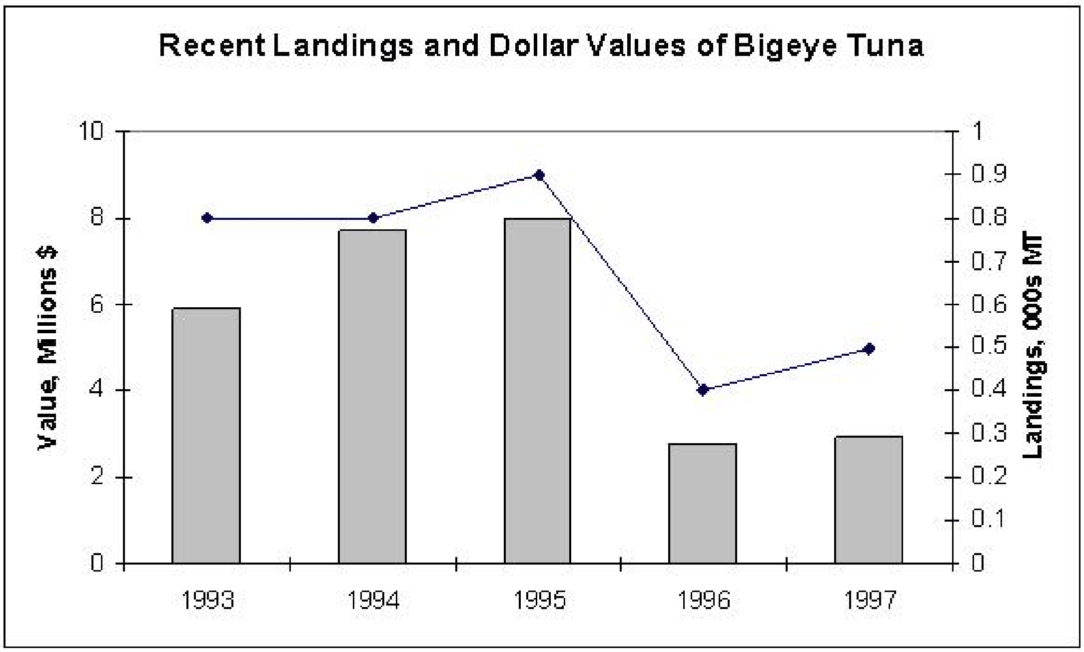


Figure H.21. ***Atlantic Cod Landings and Value***

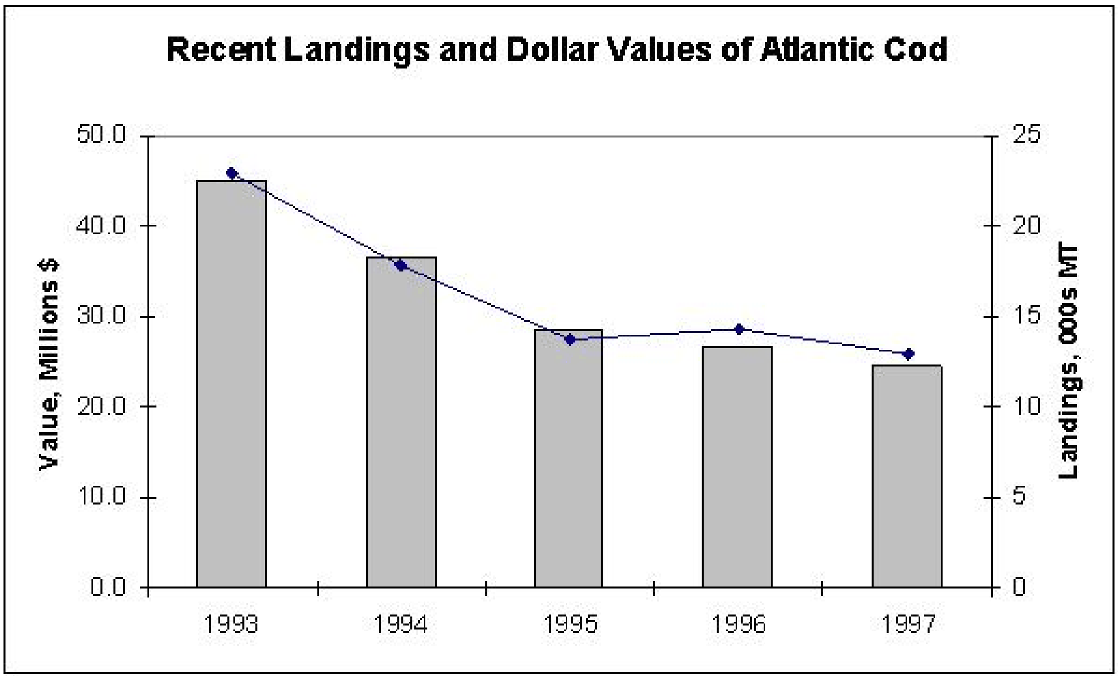


Figure H.22. ***Swordfish Landings and Value***

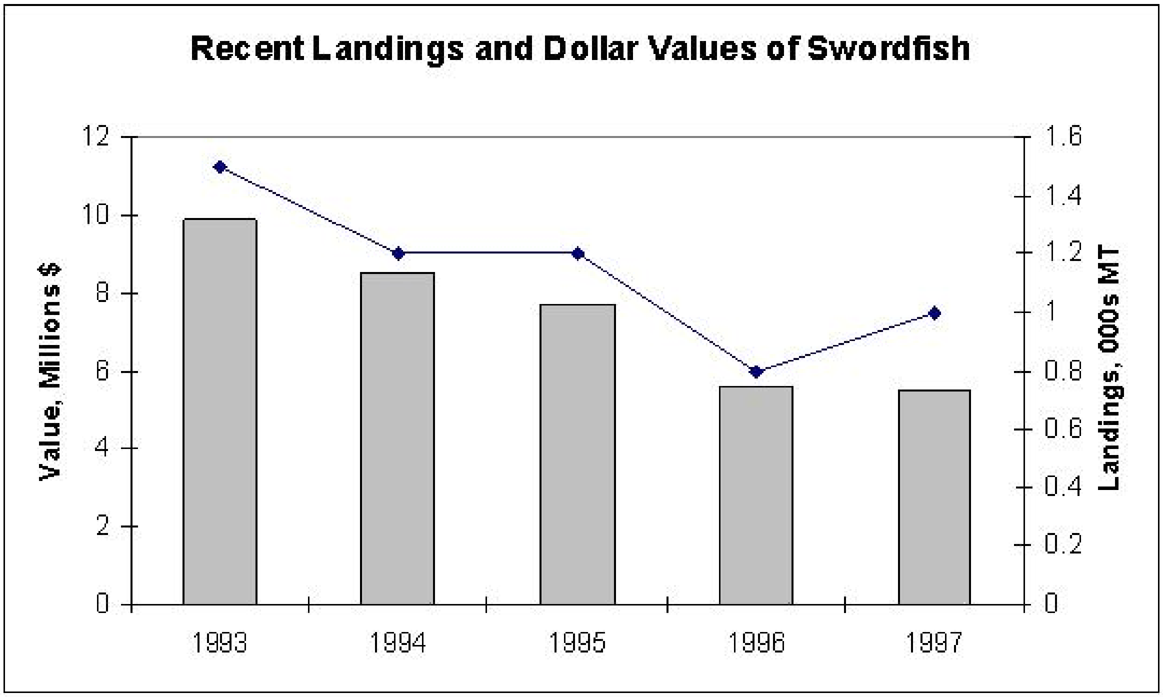


Figure H.23. ***Fraction of Georges Bank closed year-round to fishing***

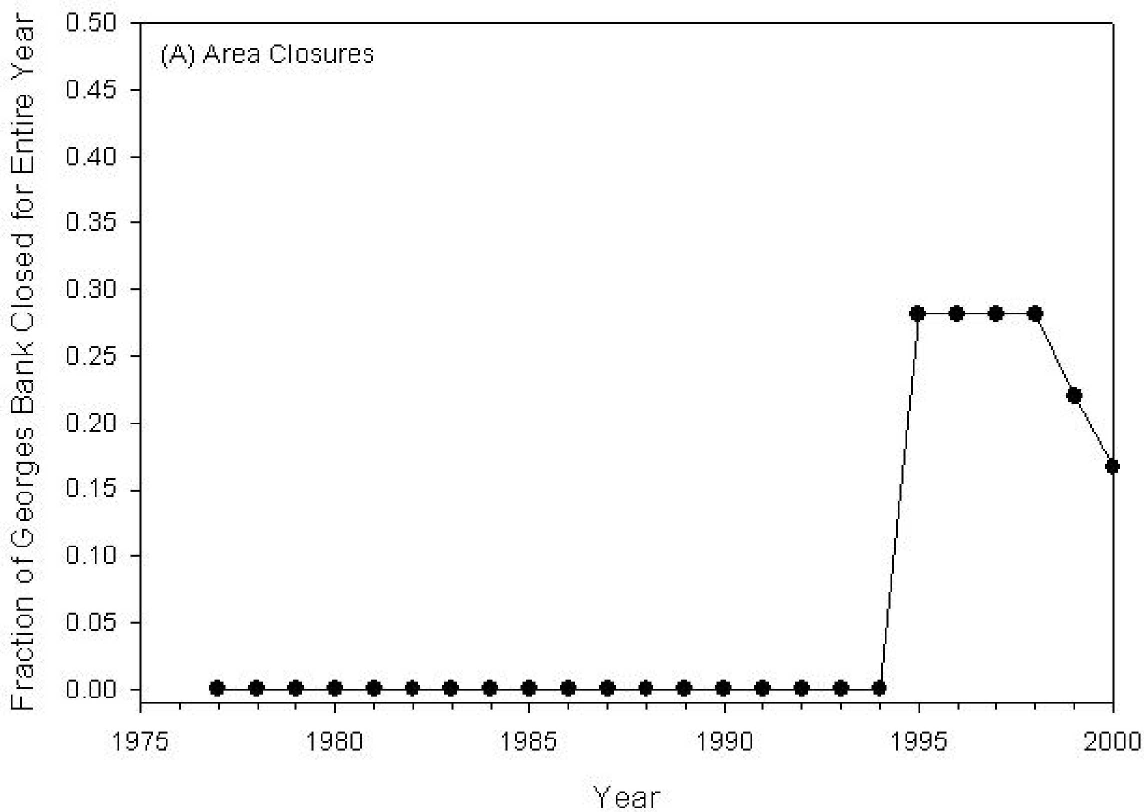


Figure H.24. ***Minimum mesh size regulations for trawl fishing nets***

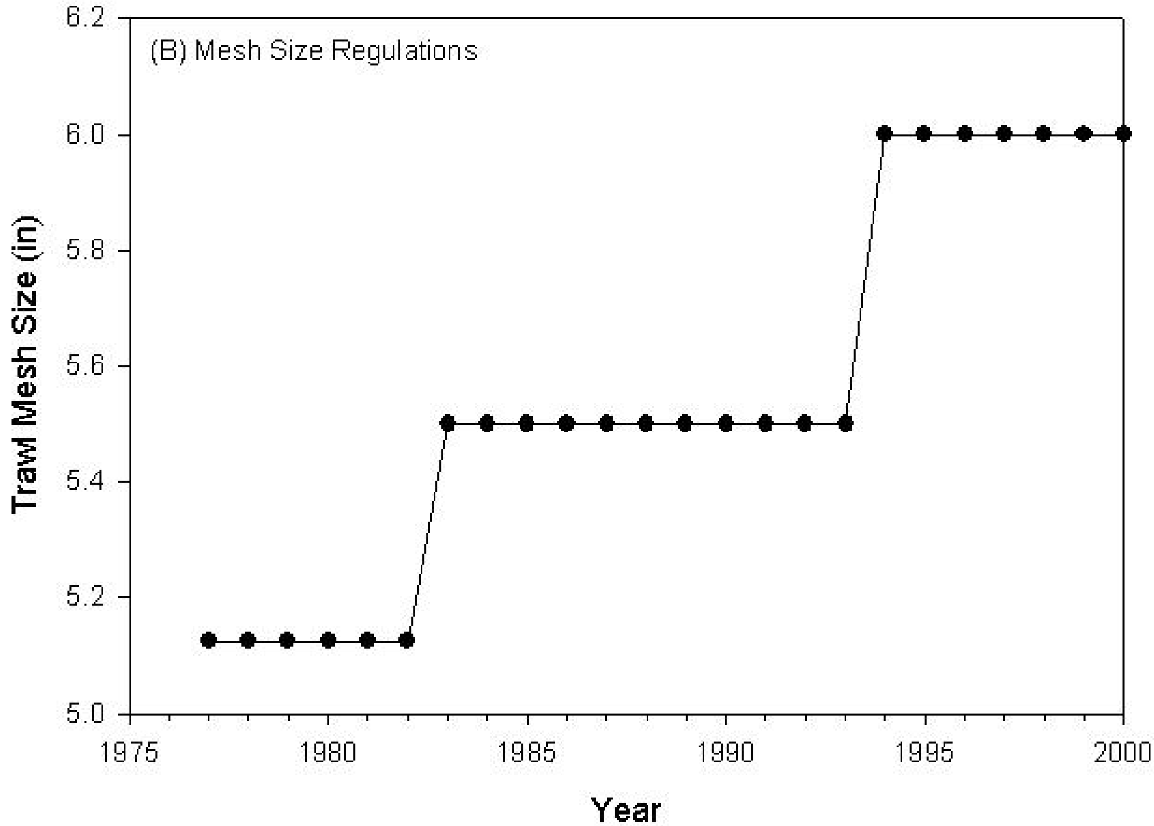
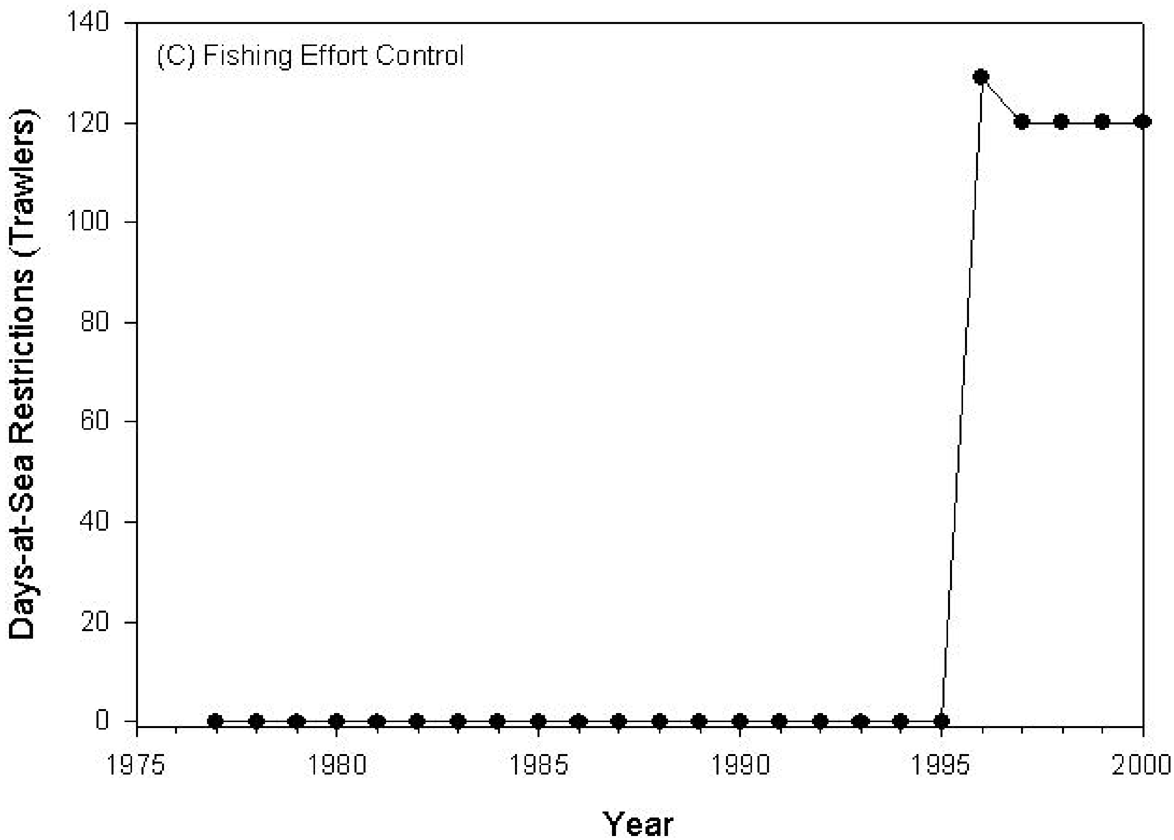


Figure H.25. ***Days-at-sea restrictions for groundfish vessels***



VI. Integration

A. Similar Patterns, Key Observations

Substantial changes in the ecosystem occurred in the late1970s to early 1980s. Change was apparent across several abiotic, biotic, and human metrics. Many metrics had a notable increase or decline during this period. Of the 123 metrics we examined with long enough time series, 44 exhibited an increase during this period. Additionally, 39 exhibited a decline during the same time. Thus, over 67.5% of the metrics we examined suggest that some event or series of events occurred in the late 1970s and early 1980s. The synchronicity of these changes also reflects the interaction among the various metrics. We explore what may have caused the changes and how the changes might be related in the next chapter. Here we want to document similar patterns among the various types of metrics.

B. Abiotic Metrics

Environmental conditions have varied through time.

Over a decadal time scale, there have been some moderate changes in water temperatures. The 1960s had cooler water conditions than the 1970s and 1980s, while the 1990s was somewhat warmer than preceding decades. It is uncertain if there is a relationship between these observed temperatures and the NAO. The offshore waters of Georges Bank and the open Gulf of Maine do not exhibit the same temperature trend as coastal waters. Within the Mid-Atlantic Bight, water masses shifted during the 1990s. There was less slope water in the Mid-Atlantic Bight in the 1990s with warmer and less saline water conditions. In the 1990s, there was also more Scotian Shelf water in the Gulf of Maine, but the effects of this cooler water may have been offset by more coastal warming so that no trend in temperature was apparent. How these changes affected the biota remains a major question.

Some short-term cycling in temperature anomalies is apparent, on the time scale of 3-5 years. However, there is no appearance of a major regime shift in oceanographic conditions such as have been documented in the late 1970s in the northeastern Pacific Ocean. Overall, the observed oceanographic metrics suggest the system is undergoing natural variation about its long-term (40 year) average conditions, with some moderate serial correlation.

C. Biotic Metrics

The composition of the biotic community has changed across different levels of organization, from zooplankton to forage fish to top predators.

Phytoplankton abundance (as measured by standing biomass of chlorophyll *a* on the offshore shelf) has remained relatively constant through time. This suggests that primary productivity in this ecosystem is relatively stable. Two caveats are that the composition of species may have changed and that the productivity is not measured by chlorophyll *a*.

Predatory release on the zooplankton community was not apparent when planktivore abundance was severely reduced by fishing. The implication of this observation is that the zooplankton community is primary regulated by bottom-up environmental forcing. In particular, given the substantial changes in the abundance of Atlantic herring and Atlantic mackerel, the primary pelagics, one would have expected the zooplankton community to increase substantially as these predators were less abundant.

It is unknown whether the benthic community has changed due to a lack of time series data. This gap in our knowledge may be important to fill and there is some ongoing research by the NEFSC directed at alleviating this gap.

The composition of the fish community has changed dramatically through time. Groundfish abundance declined dramatically under intensive harvest pressure. Squid, which are preyed upon by groundfish, increased in abundance during the 1970s as groundfish abundance declined. Similarly, American lobster catches increased following the decline in groundfish abundance. While groundfish declined, abundances of elasmobranchs, including spiny dogfish and skates, increased. Elasmobranch abundance began to decline in the 1990s, however, as fishery harvests increased from negligible to substantial levels, especially for large adult female spiny dogfish. The abundance of primary pelagics, Atlantic mackerel and Atlantic herring, declined substantially in the 1970s. In recent years, the abundance of primary pelagics has increased substantially as harvests and abundances of some predators have remained low.

D. Human Metrics

Revenues generated by the otter trawl fleet in New England, the primary component of the multispecies groundfish fishery, have declined through time. Otter trawl revenues peaked in the early 1980s and have declined since then. This long-term decline has occurred as the number of groundfish vessels has increased. Part of the increase in groundfish vessels was a federal government program to loan money to build more vessels following implementation of the Magnuson-Stevens Fisheries Conservation and Management Act (FCMA) of 1976. The impact of declining revenues and increasing vessel numbers is that this fishery is producing a smaller benefit stream and that these benefits are being divided among a larger set of participants. Overall, this would suggest that there may be less satisfaction within this fishery sector in recent years as profitability has been reduced, on average.

In a similar context, the composition of the landings of the otter trawl fleet in New England has changed dramatically through time. The increase in landings of non-groundfish species corresponds to the decrease in groundfish abundance. The behavior of the otter trawl fleet, as a top predator within the system, has changed in relation to the availability of various fishery resources. One potentially dangerous aspect of this type of behavior is that species groups may be serially depleted as the fishing fleet moves to target more abundant groups after others have been depleted. In the long term, this type of behavior is not likely to be sustainable and could result in substantial and possibly irreversible changes to the species composition of the ecosystem.

Information on the standardized fishery catch-per-unit effort (CPUE) data from the foreign and domestic fleets on Georges Bank during the 1960-1980s shows that capture decreased over threefold as aggregate fishery resource abundance declined. Such a decrease in efficiency would be expected based on bioeconomic theory for an open-access resource - this is another indication that the top-down impact of human predation on the system has been substantial. The decline in CPUE is similar to the declining trend in groundfish abundance. The declining trends in the two metrics are not identical because fishery CPUE is not likely directly proportional to abundance and is difficult to standardize when fishing practices and fishing gear have changed through time.

The harvest control rule for the Georges Bank haddock stock suggests that this productive resource has been chronically overfished since the 1930s. The long term impact of overfishing on Georges Bank haddock has led to a severe decline in haddock abundance. Although some rebuilding of this stock has occurred in recent years under restrictive management, Georges Bank haddock abundance is still well below target abundance. It seems likely that other groundfish species, for example Atlantic cod, have experienced similar long-term exploitation patterns although long-term assessment data are not available to directly support this point.

Fishing regulations on the New England otter trawl fleet, the primary component of the groundfish fishery, have increased since the implementation of the Magnuson-Stevens FCMA of 1976. One apparent result of increased regulation has been a reduction in the landings and fishing mortality on groundfishes. These decreases may have helped to foster some rebuilding of the groundfish resources. However, despite recent increases in abundance, many groundfish are less abundant than during the early 1960s, immediately prior to the intensive harvests by the foreign distant water fleets.

The behavior of the groundfish fishing fleet in recent years shows that human predators exhibit spatial heterogeneity in their fishing behavior. Cultural and socioeconomic differences exist within the fleet at the port, county, and state level and there are some obvious spatial patterns in choice of fishing location and movements among fishing areas. Some of the reasons why certain choices are made can be related directly to regulatory and political-econonic regimes, but others require further study.

One question raised by the decline in otter trawl revenues in recent years, is “Why are fishermen still choosing to fish when the economic returns are so poor?” For fisherman who consider their livelihood not simply a job but a way of life, cultural aspects of the traditional fishing communities provide other important rationales to continue to participate in the fishing fleets. Changes in fishing practices and fishing communities, such as diversification to target non-groundfish resources, have probably contributed to sustaining the fishing fleet while target species abundances have declined and regulations have increased.

E. Summary

We have observed changes in the biotic, abiotic, and human components of the Northeast U.S. Continental Shelf ecosystem over the past forty years. Despite these changes, the relative constancy of aggregate biomasses across trophic levels (e.g., phytoplankton, zooplankton, fish groups, etc.) over the time series is surprising and suggests that aggregate system biomass is resilient to perturbations applied to date. This suggests that human activities thus far have not severely eroded the productive capacity of the system in terms of bottom-up forcing. Yet the species composition at any given trophic level has changed dramatically. The changes that have been observed may be attributable to both top-down forcing (e.g., through fishing) as well as inherent natural variation (bottom-up) in ecosystem processes.

VII. Synthesis

A. Heurism, Relationships, and Generated Hypotheses

Even though we know a lot about many aspects of this ecosystem, we do not fully understand all of the processes and mechanisms that have generated the range of conditions we have observed in this ecosystem. The challenge remains for us as scientists to understand ecosystem function and structure.

The working group listed some of the more important questions related to our understanding of this ecosystem. We list this set of questions and either answer them based on the data presented in this document or recommend research to address them. In many respects, these questions represent some of the key hypotheses of how this ecosystem is structured and functions.

B. Principal Question

What are the natural and anthropogenic factors underlying change (or variability) in the northeast U.S. continental shelf ecosystem and its subsystems?

We may never be able to quantify all of the processes in this ecosystem. Even partially addressing this question will be helpful to our understanding of this ecosystem.

C. Major Questions

1. System

What are the important changes in biota, oceanography, and fisheries through our time period *of observation, by subsystem or finer scale as needed (subsystem-see below)?*

We have documented changes in the ecosystem over our period of observation; see the previous chapter for a more detailed description of these changes. Many of these represent an order of magnitude (or more) of change. That we can ascertain the status of an ecosystem such as this one is not trivial.

Has there been a change in relative energy flux through pelagic and demersal fish populations through time - a trophic regime shift (by subsystem)?

Yes. The system is now “horizontal” (dominated by pelagic species that migrate) rather than “vertical” (demersal species with higher site affinity) and the biomass, energy fluxes, and community structures reflect this (see Figure 3 in Link 1999).

What are the sources of temporal and spatial variation in fish and marine mammals in the system due to climate change, bottom-up forcing (temperature, habitat loss/degradation inshore, impacts of toxic chemicals inshore, and nutrients), trophic cascades (impacts of selective predation by fish/marine mammals, prey refugia, and fisheries harvesting), etc.?

Certainly these are all important potential forcing functions. At this time it is difficult to clearly determine the relative contribution of each source of variability to the overall variability of the biotic community. Future multivariate analyses will need to partition this variance.

What are the potential consequences of a regime-shift between a demersal fish/benthos-dominated ecosystem to a pelagic fish/plankton-dominated system?

We're not sure anyone knows the full ramifications of this type of shift. Certainly there are a few hypothesized outcomes (e.g., slower recovery of groundfish, predation on demersal fish larvae by pelagic planktivores, removal of energy off the shelf or to different parts of the shelf, increased competition among different components of the system, increased ctenophore predation, etc.), but those remain to be tested.

What are the relative strengths of couplings within and between benthic and pelagic systems? How would this vary by oceanographic region (Gulf of Maine, Georges Bank, Mid Atlantic Bight, etc.)? How strongly are regions linked? (What would we be leaving out when we go to smaller/higher resolution models?)

We do not know the relative strength of pelagic versus benthic subsystem couplings, but in general, the system appears to be loosely coupled.

Is there a characteristic predictability/stochasticity of dynamics for each region/component? (How reasonable is "deterministic" management?)

It is difficult to say because of the multiple and simultaneous processes occurring in this ecosystem. We think a standard signal (i.e., pattern) may be generally detectable for key processes. Yet being able to predict specific components of this ecosystem, and evaluating their associated stochasticity, remains difficult.

What are the relative effects of environment vs. fishery on ecosystem/community/population structure and dynamics? (How should we modify current population dynamics models used in *assessments to reflect this?)*

It is fairly clear that in general, the dominant factor influencing fish populations is fishing. The environment is then a key second forcing function that can determine the recovery trajectory. The environment also can strongly dictate the level of productivity of the system or community or a population.

2. Abiotic

Is there evidence of an oceanographic regime shift on a system-wide scale, or by subsystem?

The evidence is unclear. Some metrics show an increased warming in recent times and a change in the NAO, yet the high amount variability and closer examination suggest that the major physical processes acting in the Northeast U.S. Continental Shelf ecosystem are generally the same ones (albeit at slightly different times or magnitudes).

Are there trends in offshore, nearshore, and estuarine habitat quality? What indicators of quality exist for the last few decades, and is there any way to extrapolate back a few more decades?

We are unlikely to have the data to answer these questions. Examining sediment cores along transects may be one feasible approach to address this issue.

Is there any spatial/temporal coupling of physical environment and seasonal migrations of biota between estuaries, coastal waters, continental shelf, and continental slope?

We do not know if we have the data to answer the question for couplings and migrations between estuaries and nearshore to the offshore waters. Along the continental shelf and slope, data exists to describe seasonal migrations of various biota. These patterns have been documented elsewhere (e.g., Grosslein and Azarovitz 1982; Bowman et al. 1987; Overholtz et al. 1991).

What are the potential consequences of nitrogen enrichment (from the atmosphere and land use activities in coastal watersheds) of estuaries and coastal waters on the food chains supporting fish/marine mammals and as a source for harmful algal blooms (HABs)?

We do not know the answer to these questions. Satellite imagery and nutrient monitoring would help to better address these issues.

How is fishery performance affected by environmental factors (human behavior, fish behavior/availability)?

In a general sense, the weather greatly influences fish and fisher distribution. In a more specific sense, it is uncertain how the environment influences catch rates.

What is the verdict on environmental change in the Georges Bank ecosystem; is it stable or changing?

It is both stable and changing, depending upon the scale of observation and the particular environmental metric examined. Again, some metrics show an increased warming in recent times and a change in the NAO, yet the high amount variability and closer examination suggest that the major physical processes acting in the northwest Atlantic are generally consistent (albeit at slightly different times or magnitudes).

3. Biotic

What appear to be the dominant top-down and bottom-up effects in the food chain, by subsystem?

Regardless of spatial consideration, fishing is the dominant top-down effect. This effect may or may not propagate through lower trophic levels. Predation is a less dominant top-down effect in this ecosystem. It is unclear to what degree physics, nutrient input, etc., influence lower trophic levels as bottom-up effects. The physical conditions may create local conditions that alter the magnitude of species and fisheries interactions, which may indirectly affect those lower trophic levels.

What appear to be the relative importances of top-down and bottom-up effects on commercial fish and invertebrate recruitment strengths through time?

Fishing is a very strong effect, but environmental conditions are also important. Allocating importance in terms of proportional influence remains to be done. Recruitment remains a particularly difficult issue.

What are the impacts of increasing pinniped populations on fish/endangered species (i.e., Atlantic salmon; sturgeons; etc.) and potential interactions with fixed gear and aquaculture?

We don’t have the data to answer this question at this time.

Are production and net production stable or changing over time in the Georges Bank ecosystem?

The standing biomass of the full ecosystem and sub-components of it (e.g., phytoplankton, zooplankton, various guilds, etc.; c.f., Figures B.7-B13, B.27a-l; O'Reilly and Zetlin (1998)) appear to be roughly constant over time. However, the particular species composition in any one of these groups has changed across time. Thus, the productivity of the different groups and the entire ecosystem is not readily known at this time.

Are zooplankton numbers per m^3 stable or changing over time in the Georges Bank ecosystem?
They appear to be roughly consistent across time, albeit with notable changes in species composition and variation (c.f., Figures B.7-B.13).

4. Human

Do ecosystem-level analogues to single species reference points exist? What about control rules?
There are most likely ecosystem-level analogues. The suite of metrics described in previous chapters are promising possibilities to include in decision criteria models and analyses.

How have anthropogenetic influences other than fishing affected the status of the ecosystem? For example, can changes in the ecosystem be related to pollution? Or, what levels of pollution would be required to have a detectable impact on the ecosystem?
We do not know at this time.

Can ecosystem status be projected? Can current and projected ecosystem status improve management advice from single species stock assessments and forecasts? For example, *recruitment of species X is expected to increase/decrease in future due to changes in temperature, phytoplankton, food web, increase/decrease in species Y, etc. Can the same be done for fishery management reference points as well?*

We think that this certainly can be done, but it remains to be demonstrated in the current management and science institutional context.

Can we offer guidance regarding placement and timing of closed areas that goes beyond a particular commercially important species? That is, how will predictions of ecosystem level impacts of different management measures such as closed areas, mesh size changes, species targeting, etc., influence management strategies?

We think that this certainly can be done, but it remains to be demonstrated beyond generalities.

Is there some utility of closed areas for groundfish as a fishery management tool and as a means for increasing biodiversity/fish productivity, both inside and outside of the closed areas? Similarly, what is the role of Marine Protected Areas (MPAs) as a fishery management tool?

Yes. We do not directly present the type of information to answer these questions in the previous chapters (but see figures H.23, B.1-B.4, B.23, B.24) and refer the reader to Murawski et al. (2000) and Brown et al. (1998).

What are the tradeoffs between optimum fisheries harvesting approaches and maximizing the "net economic return" to the nation from the use of these public resources?

The specifics are uncertain, but in general and based upon first principles we would probably be trading short-term maximization of profit with long-term profit and resource sustainability. Much further work remains to adequately address this issue.

What is the role of socioeconomic forces on the harvesting behavior of commercial and recreational fishers and how do these relate to effective fisheries management strategies?
This is an area in which we have little data. Certainly the broad study of values and valuation would shed some insight into this question, particularly why fishers and fishing communities attempt to persist in an often unprofitable activity.

What is the combined economic value of the commercial stocks (not landed value)? Is it consistent with the long-term notion of sustainability? If not (probably not), what is the magnitude of economic waste each year (these questions/issues involve "green accounting")?
These are difficult questions to address.

What are the implications of systems thinking (e.g., biological and technical interactions) for single-species management and Maximum Sustainable Yield (MSY)? Is there a better systems concept, such as resource portfolios, for fisheries management?
The implications are that some management advice may need to be qualitatively adjusted or modified, probably to be more conservative. Certainly different approaches would be useful to help understand an ecosystem, and we advocate as holistic an examination of the ecosystem as possible, but can not necessarily espouse one approach over any other at this time. Quantitative approaches to alter single species reference points and targets remain a large and fruitful area of

research.

What are the design characteristics and functions of an institutional arrangement that could employ ecosystem-based management of fishery (and other marine) resources? How do these compare to the current Council/NMFS management arrangement?

It is not likely that we will know the answer to this for some time. Changes to the SFA/MSFCMA may force us to reexamine our institutions. Accounting for other laws (e.g., MMPA, ESA, NEPA, etc.) may also contribute to this reexamination. Comparisons to other regions and countries may be an useful first step to address this question.

Have major fishing episodes (i.e., ICNAF, recent USA) permanently altered the ecosystem?

Certainly they have altered parts of the ecosystem. To what extent these changes are "permanent" or irreversible is unknown. A formal stability and steady state analysis would be required to address this question more rigorously.

D. Summary and Conclusions

Although integrating and synthesizing the information from a diverse set of disciplines is a difficult task, there is value in inter-disciplinary working groups. We would encourage the expansion of this approach to include the perspectives from other disciplines working on marine ecosystems.

It takes substantial and multiple time series of metrics and associated monitoring to assess the status of a system. No one metric best described the status of the ecosystem, even though many of the metrics demonstrated similar trends and many of the metrics similarly captured the directionality of key processes and relationships. It is clear that several of these metrics should be examined concurrently. Examining just one or a few may be misleading. This work is distinct from those that focus on a single process in that it integrates all these considerations at once. If one uses the leading indicators of any national economy as an analogy, a similar approach is useful for indexing the status of an ecosystem.

The change observed for many of the metrics during the late 1970s and early 1980s corresponds to the passage of the first Magnuson-Stevens Fisheries Conservation and Management Act in the late 1970s, which resulted in the expansion of the domestic fleet and a subsequent increase in groundfish landings beyond sustainable levels. Changes in the physics of the ecosystem were also occurring during that period. These two considerations, along with their derivatives (e.g., habitat alteration, changes in competitive balance among species, temperature induced migrations, recruitment success, switching targeted species, etc.), were probably the causal (at least initially) events that led to the observed changes (and lags thereof) in the observed ecosystem metrics.

From this work we have developed a unique compilation and understanding of trends, magnitudes, and relationships among key processes. The knowledge from this study is highly heuristic and as such inherently valuable. We recommend regularly assessing the status of ecosystems at appropriate time scales and reference points, analogous to single species fish stock assessments.

E. Acknowledgments

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